INSTITUTE OF
PAPER CHEMISTRY
Appleton · Wisconsin

GENETIC IMPROVEMENT OF LARCH

Project 3409

Report Seven
A Progress Report
to
MEMBERS OF GROUP PROJECT 3409

February 15, 1987

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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TABLE OF CONTENTS

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

GENETIC IMPROVEMENT OF LARCH

SUMMARY

A total of 139 selections have been acquired for the larch project. Additional clones are being sought from Canadian larch tree improvement groups. The addition of tamarack to the project is being considered as a means to deal with frost prone and poorly drained sites.

Last year's grafting program suffered from an unusually high mortality rate due to root stock storage problems and an early spring warm period that caused bud break on scion sources before they could be collected and grafted in a dormant state. Storage conditions have been changed and repeat problems are not expected.

One hundred twenty-six clones are established in the Greenville arboretum. Growth was good this past year and flowering has begun on the first grafts established in 1981. Several small crosses were made this past spring to evaluate plastic *vs.* paper pollination bags and several pollen sources. All of the crosses made with plastic bags failed. Most crosses made with paper bags produced viable seed, although of low quantity. A European larch by tamarack cross was made and seed was collected.

Large quantities of known origin European larch seed were acquired for plantation establishment by cooperators. The seed was expensive, ranging from $415-500 per kilogram, and difficult to find.

Frost injury was severe in a number of plantings and in at least one seed orchard this past spring. An unusually warm spring induced early flushing of larch and later frosts damaged new growth. Several plantings and seed orchards were rated for injury and degree of recovery. Differences between seed sources and clones were noted with the least damaged sources originating in Poland and the Sudeten Mountain region. An exploratory research project has been started, using IPC funds, to evaluate frost tolerance/injury under controlled conditions.

Two of three seed orchards planted are becoming established, while the third was lost to severe frost injury. The damaged orchard will be relocated further south in Wisconsin. A fourth orchard was planted near Escanaba, Michigan this past spring.

Four replicated field trials were measured this fall along with several field plantings. Sudeten seed sources continue to be among the best growers. Frost injured several plantings, causing reduced growth in the older ones and mortality in the younger ones.

A site preparation herbicide trial that was treated in the summer of 1985 was planted with larch, hybrid, aspen, and red pine the spring of 1986 and was evaluated in 1986. Best treatments for controlling vegetation were Velpar L, Oust, and Arsenal. Bare root hybrid larch had the best survival and growth followed by hybrid aspen and container red pine. Growth and survival will be evaluated in 1987 to determine long-term effects of treatments.

A red pine pulping study contrasting 24-year-old thinnings with 55-year-old mature wood was completed. Red pine is increasing as a conifer fiber source and it was believed useful, given the lack of red pine pulping information available, to evaluate it under the same cooking conditions as the larches and jack pine. The results provide a point from which the usefulness of larch can be further examined.

Kappa 50 and kappa 30 pulps were prepared from bark-free chips of 24-year-old (thinnings) and 49-year-old (mature wood) red pine. The resulting pulps were evaluated for strength and compared with previously evaluated jack pine control pulps and pulps from European, Japanese, and hybrid larch. Of particular interest was the usefulness of thinnings from red pine plantations as a conifer fiber source. The red pine thinnings pulped at a similar rate as the mature red pine chips, but both sources pulped with greater ease than the jack pine control chips and wood from the three sources of larch. Pulp yields for red pine thinnings were 2 to 3% lower than for the mature red pine chips and 2 to 3% lower than European and hybrid larch. Pulps from red pine thinnings developed adequate breaking length, but at a breaking length of 10 km they had 32% lower tear, 13% lower burst, and 20% lower tensile energy absorption in comparison with pulps from 18-year-old European larch plantation grown trees.

INTRODUCTION

The evaluation and development of larch as an additional conifer fiber source for the Lake States and Northeast remain the principal objectives of Project 3409. The pulping trials undertaken at the beginning of the project have clearly shown the suitability of larch as a pulpwood species. A red pine pulping trial completed this past year demonstrated the superior nature of larch fiber in comparison to what is becoming the industry standard for Lake States conifer fiber.

Although establishment problems have occurred, primarily from spring frost injury, work is being initiated to identify the most frost tolerant sources and to develop guidelines for planting larch. To further the usefulness of *Larix* under those conditions it is being proposed that tamarack be included in the current project. The amount of land suitable for tamarack and the potential usefulness of tamarack hybrids would seem to be adequate justification for its use. In anticipation of its inclusion, a pulping study has been initiated that contrasts young *versus* old tamarack and will evaluate the same pulp and paper properties tested in previous studies.

One of the main objectives of the larch project, the establishment of seed orchards, is being met despite the loss of one newly established orchard this past spring. The sporadic availability of European larch seed and the high value of that seed is an inducement to bring cooperator sources of seed into production as soon as possible. We recognize that these first orchards have not been progeny tested, but we believe that the interim risk associated with these first orchards until second generation orchards can be established remains acceptable. A long-range breeding plan is being developed. Controlled pollinations were made this past spring with a modest degree of success, and it is planned to expand upon that work this coming spring.

The 1986 early warm spring and late spring frosts should be viewed as a positive development in that it has made us carefully reevaluate our thoughts on seed orchard locations. In addition, damage to field plantings has helped identify those sources which could have frost problems in northern frost-prone sites. The impact of frost is being assessed early in the project before large-scale plantings of frost-prone sources have been put in, and that assessment will lead to guidelines for both seed origins and location of plantings.

SELECTION AND PROPAGATION

SELECTION

A total of 139 selections have been acquired for the larch project. Although this is considered a minimum number of clones, it is adequate to initiate progeny testing. The larch clones we intended to acquire from tree improvement programs in Canada were not sought last winter because of rootstock problems. Contacts will be made for this year's grafting program and additional larch clones will be added as they become available and if plant quarantine regulations can be satisfied.

The addition of tamarack to the larch project is under consideration. Several selections will be made this winter, and pollen will be collected from them in the spring for use in hybridization with European larch. Further consideration of tamarack occurred because of frost damage to exotic larches on frost-prone sites and because of the usefulness of tamarack on poorly drained sites. A discussion regarding the addition of tamarack to the larch project will be part of this year's annual meeting.

1986 GRAFTING

An overwinter storage problem with rootstock contributed to a failure in the 1986 grafting program. Apparently the bareroot stock intended for both grafting and field planting either dried and/or was subjected to fluctuating temperatures in a newly constructed pole barn at the IPC Nursery. A contributing problem may have been the condition of the stock when it was received from the contract grower in the fall of 1985. Root systems were dry on a large number of seedlings and the fall lifted stock still retained a considerable amount of green needles which may have contributed to further desiccation and low vigor.

Additional problems occurred with scion material. Scions shipped from Maine failed to flush after grafting. Scions collected from the Greenville arboretum late in the grafting program had begun to break dormancy before they were collected and did not form an adequate union with the rootstock. The combination of poor rootstock and scion failure resulted in the loss of 993 grafts out of a total of 1062. This is in stark constrast to previous annual larch grafting, where success rates ranged from 80-90% of over 1000 grafts made.

The conditions that led to the loss of last year's grafts have been changed. In particular, fall lifting was delayed until November, when the needles were brown and being shed. Storage conditions are being held constant, with constant temperatures and routine inspection to assure no drying occurs. The effect of an early spring warming period on scion quality was quite apparent, and scion collections will be made before any chance of a warm spell.

GREENVILLE ARBORETUM

Two European larch clones were added to the arboretum at Greenville this past spring, bringing the number propagated and established to 126. Several clones were moved from wet areas within the arboretum to better drained locations. The wet areas will be replanted with tamarack selections.

The growth and survival of the grafted clones in the arboretum has been very good as illustrated in Fig. 1. Many of the clones that have been in the arboretum for two years doubled their height during this past growing season, and those clones established longer than two years had height growth over three feet. The form of most grafts is good, and the stakes used to support them during the first two to three years of establishment have been removed. The arboretum is being mowed, and each graft has a 6-foot diameter area around it sprayed with Roundup.

Figure 1. A five-year-old Japanese larch graft in the Greenville Arboretum. Growth and vigor of grafted clones within the arboretum are very good, and cone production is beginning.

Flowering has begun on the older grafts, and information on pollen shedding times and cone production is being collected. Most of the cones produced this spring were collected this fall, and seed was extracted to determine the germination rates. The European larch seed had not been extracted at the time this report was being prepared, thus no germination data were available. Seed from seven Japanese larch clones was extracted and germinated. Germination rates ranged from 0-6% with an average of 1.5%, reflecting a low rate of pollen production. The information is being collected to gain an insight for the age at which flowering and seed set can be expected. In addition, the synchrony of pollen shedding between clones will be determined to aid in the selection process of clones for future orchards as well as in the determination of those clones in present orchards that may not be outcrossing.

CONTROLLED POLLINATION

To take advantage of the flowering that has begun in the Greenville arboretum and to gain familiarity with controlled pollinations of Larix as the first step toward progeny testing, a series of small crosses was made this past spring. Three 5-year-old seedlings from a Sudeten seed source (XLD-3-79) that had been planted in the arboretum as part of an isozyme study, a European larch clone (LD-3-81), and a Japanese larch clone (LL-11-80) provided the female inflorescences. Fresh pollen was collected from a Japanese larch selection (LL-4-59,S-1) in the Greenville Arboretum and from a tamarack selection from Starks, Wisconsin. Stored pollen from a collection made the previous spring from a Japanese larch selection (LL-4-59) in an IPC replicated trial on the Clintonville Test Area was also used. Pollination attempts the previous spring indicated that plastic pollination bags may not be suitable. To further evaluate their suitability, plastic bags were included in one half of the crosses made this past spring with the other half utilizing brown kraft paper bags.

It is apparent from Table 1 that plastic bags are unsuitable for larch pollination work. Of the 49 cones pollinated within plastic, only one was collected. Field observations indicated that the cones within plastic bags were killed by heat buildup. There was also considerable moisture in the bags. Neither of these problems occurred with the paper bags, where 29 of the 39 cones pollinated were collected.

The germination rates given in Table 1 are based on total seeds removed from dissected cones. The germinated seeds were transferred to soil and their hybridity will be confirmed. The putative European larch x tamarack hybrid seedlings will be asexually propagated to increase numbers and will be established in the field for growth observations.

Dr. D. P. Fowler of the Canadian Forestry Service has produced both Japanese x tamarack and European x tamarack hybrids. His comments indicated that the tamarack hybrids were not spectacular in growth and were difficult to produce but that backcrossing a Japanese x tamarack hybrid onto a Japanese larch has possibilities and may be frost resistant. He also thought that a Japanese larch x Siberian larch hybrid had promise and would be easier to produce than tamarack crosses. Fowler suggested that the best approach would be to produce the frost resistant hybrids or tamarack x tamarack crosses and vegetatively propagate them to increase numbers using either hedged seedlings as a source of cuttings or through a tissue culture system.

Controlled pollinations will be made again this spring to evaluate crossing methods and to begin producing tamarack hybrid seed and seed for use in progeny testing of European larch clones being established in seed orchards.

Dr. Michael Greenwood of the University of Maine has offered to provide pollen from tamarack selections for a small number of crosses this coming spring.

Table 1. Results of controlled larch pollination.

Clone	Replication	Bag Type	Pollen[a] Source	No. Cones Pollinated	No. Cones Collected	Germination, %
XLD-3-79#6	A	Plastic	2	13	1	5
	B	Paper	1	5	3	2
	C	Plastic	3	7	0	--
	D	Paper	2	4	3	3
	E	Plastic	1	3	0	--
	F	Paper	4	3	0	--
XLD-3-79#8	A	Plastic	2	8	0	--
	B	Paper	1	4	3	9
XLD-3-79#9	A	Plastic	2	8	0	--
	B	Paper	3	12	12	7
	C	Plastic	4	6	0	--
	D	Paper	1	8	8	6
	E	Plastic	2	6	0	--
LL-11-80	A	Plastic	2	2	0	--
LD-3-81	A	Paper	1	6	0	--
	B	Plastic	3	2	0	--

[a] 1 = Stored LL-4-59 (Japanese larch) pollen.
2 = Fresh LL-4-59,S-1 (Japanese larch) pollen.
3 = Fresh tamarack pollen.
4 = Control, no pollen.

SEED AVAILABILITY

European larch seed continues to be expensive and difficult to acquire. Twelve kilograms were purchased for cooperators this past year at $415-500 per kilogram. Smaller quantities of selected seedlots were also acquired for use in provenance testing by the larch project. Seed from two Sudeten clones in a West German seed orchard that have shown good frost recovery was sought, but the orchard has not flowered for the past six years. There is concern that the orchard containing these clones is being affected by air pollution, and the Germans now suspect this is the reason for the lack of seed production.

European larch seed from the Tatra and Sudeten regions continues to show the most promise for use in the Lake States and Northeast. A large amount of seed from two provenances within the Tatra region was available this past year, but we are reluctant to have large acreages of any one larch source planted; thus we acquired only a modest amount of that seed. Provenance differences are being noted in replicated plantings for both growth and frost injury, and until those differences are better understood it is recommended that only small quantities of any one source be outplanted.

FROST INJURY TO LARIX

Plantation and replicated provenance trial establishment in 1986 was hampered by late spring frost injury to succulent larch needles and stems. Although injury has been noted in previous years, a particularly high incidence of frost damage was incurred this past spring. A number of plantings were evaluated for both injury and recovery. Climatological records were reviewed to determine the frequency of the weather conditions that led to the damage noted this past spring. Laboratory methods for screening seed sources and clones are being considered as well as in-field evaluation of latitudinal and topographic effects.

FROST HARDINESS IN TREES

The ability of trees to withstand cold temperatures increases during the fall, reaches a maximum during winter, and decreases in spring to a minimum during summer. The ability to withstand freezing temperatures is developed primarily by growth cessation brought about by temperature changes and photoperiodic effects.[1,2] Greenhouse grown plants are given hardening-off regimes that employ a lowering of temperatures and shortening of day length to induce bud set and lignification of stems in preparation for overwintering without damage from freezing. Exposure of trees to low temperatures increases hardiness, but only dormant trees develop a resistance to very low temperatures. Late spring frosts are of particular concern for all tree species. Exposure of trees to unseasonably high temperatures early in the spring decreases resistance to low temperatures. A freeze following a period of warm weather, as happened this past spring, will injure trees more severely than a frost that follows a period of cold weather.

Changes within a twig that lead to frost hardiness when growth ceases are decreased water content and cambial activity and increased sucrose and osmotic concentration. Spring frosts are considerably more damaging than low winter temperatures and fall frosts because the physiological conditions for frost hardiness are being reversed. Varying degrees of freezing injury within a single larch tree are due to different stages of bud and shoot activity as well as exposure to varying temperatures around the tree. After injury, surviving dormant buds flush and new growth is produced. The extent of freezing damage and thus number of surviving dormant buds affects the ability of larch to recover (Fig. 2).

1986 SPRING FROST DAMAGE

Observations of larch plantings this past spring indicated widespread freezing injury had occurred. A two-year-old replicated trial on a very sandy site (which typically warms up early in the spring) was lost, and one seed orchard was severely damaged and will have to be relocated. A numerical rating system was used to evaluate the extent of injury to plantings and seed orchards. Recovery from the spring injury was rated in late summer. The rating systems for evaluating damage and recovery are given in Tables 2 and 3.

Climatological data from recording stations near several plantings were examined to determine the frequency of the weather conditions that led to this spring's frost damage. It became apparent that the 1986 average April temperature, across the northern third of Wisconsin, was 5.0°F higher than normal, and temperatures from stations near plantings were 5.5-7.0°F higher than normal. May was also a month of greater than normal temperatures.

Figure 2. The photograph on the left depicts the spring frost damaged lateral branches on the bottom two-thirds of an individual from European larch seed source XLD-3-79. The photograph on the right illustrates recovery from spring frost damage.

Table 2. Spring frost damage rating system.

1 = 0-10% of needles and shoots injured

2 = 11-25% of needles and shoots injured

3 = 26-50% of needles and shoots injured

4 = 51-75% of needles and shoots injured

5 = > 75% of needles and shoots injured

Table 3. Frost damage recovery rating system.

1 = Undamaged terminal or vigorous lateral bud showing apical recovery

2 = Apical recovery, lateral branches having more than 75% foliage, good vigor

3 = May or may not have apical recovery, lateral branches having more than 50% foliage, fair vigor

4 = Damaged leader, no apical recovery, lateral branches having more than 25% foliage, poor vigor

5 = Damaged leader, no apical recovery, several damaged laterals, less than 25% foliage, very poor vigor

6 = Dead apparently from frost, evidence that tree flushed in spring and was severely damaged by frost

The warm temperatures that occurred in Wisconsin this past spring created a condition where larch broke dormancy early and produced shoot extension and needle growth greater than normal. A cold period that occurred on and around May 20 appears to have caused much of the damage. In contrast to the Northern Wisconsin frost damage, several larch plantings in Northern Minnesota sustained minor to no frost damage this spring. Although climatological data were not reviewed, comments from local foresters indicated that the early spring warm conditions present in Wisconsin were not present in Minnesota. Over the past several years, observations of Minnesota larch plantings have shown less frost problems than plantings in Northern Wisconsin.

The frequency of a spring similar to this past year's was determined from Wisconsin climatological records.[3] Table 4 provides a summary of the April temperatures present at three sites in Northern Wisconsin.

Table 4. April temperature conditions for three sites in Northern Wisconsin.

Location	30-Year Temperatures[a]			1986 Temperature		
	High	Low	Av.	High	Low	Av.
North Pelican (46° 8' lat. 89° 53' long)	51.3	28.8	40.1	56.0	35.1	45.6
Rest Lake (46° 8' lat. 89° 42' long)	52.2	29.2	40.8	58.5	32.4	45.5
Newald (45° 47' lat. 88° 42' long)	53.1	27.1	40.1	59.8	34.0	46.9

[a]Degrees Fahrenheit, data compiled from years 1955-1985.

Figures 3, 4, and 5 were taken from the Yearbook of Agriculture, 1941 and illustrate the average dates for the last killing frost in spring.[4] The isotherms illustrated in these figures were derived from data acquired over the period 1899-1938. Superimposed on these figures are the location of larch plantings and whether frost injury occurred this past spring. With the exception of Minnesota, the plantings with the most severe incidence of frost damage occurred in regions with the last killing frost later than May 20. There are a number of exceptions, most notably in Northern Minnesota, where bud break may not occur as early as in other locations within the Lake States.

Site conditions also influence the incidence and severity of frost. Foresters frequently encounter areas within their management units that have a history of frost damage. These areas vary in size but share common features that contribute to frost problems. They frequently freeze at night, generally as a result of being concave land forms. Factors which impede air movement can also affect the distribution of nocturnal temperatures and produce microclimates. Cold air is heavier than warm air, and under the influence of gravity flows

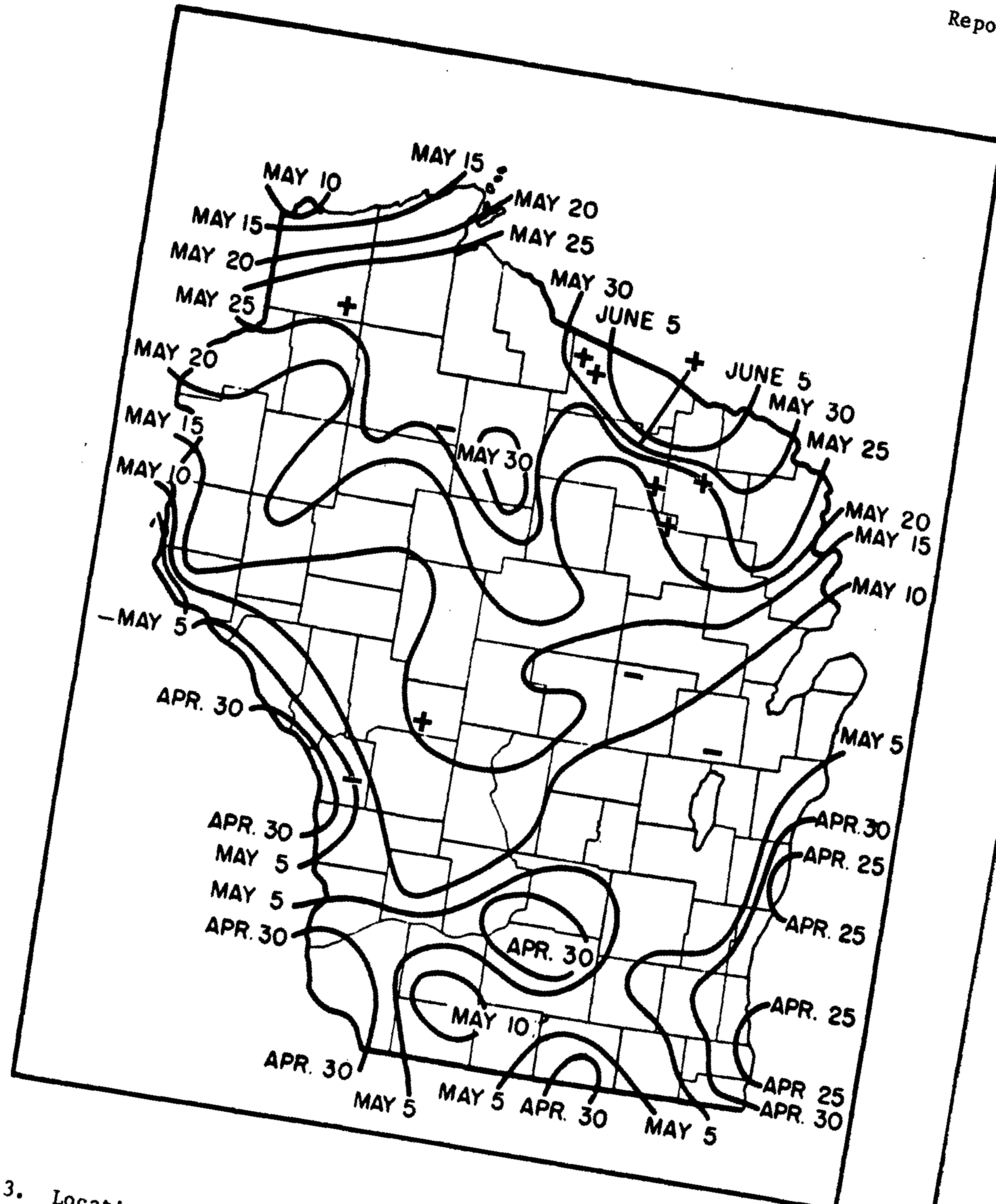

Figure 3. Location of Wisconsin larch plantings observed for frost injury. Isotherms delineate dates of last killing frost in spring. A plus sign (+) indicates injury noted; a minus sign (-) indicates minor or no injury.

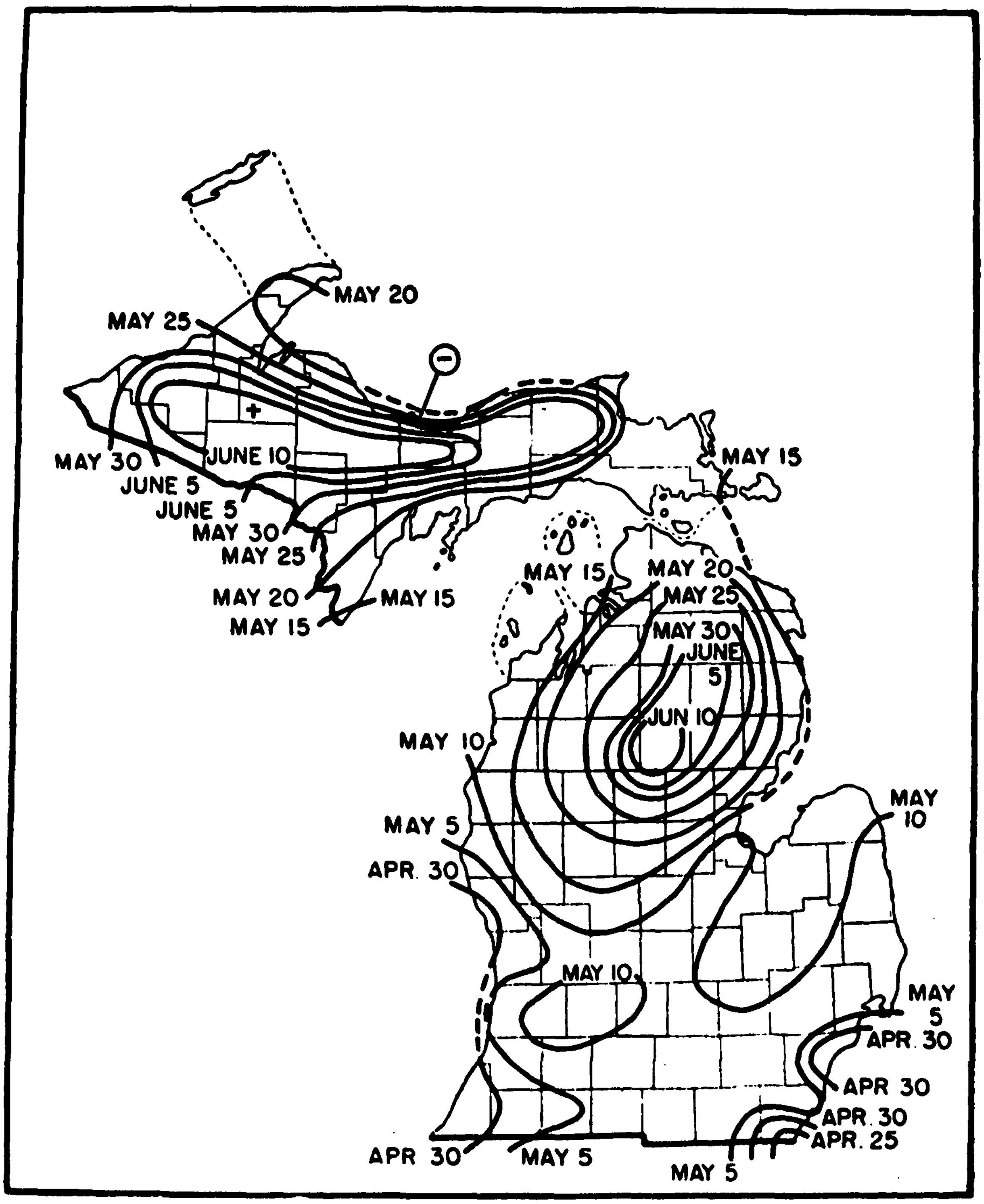

Figure 4. Location of Michigan larch plantings observed for frost injury. Isotherms delineate dates of last killing frost in spring. A plus sign (+) indicates injury noted; a minus sign (-) indicates minor or no injury.

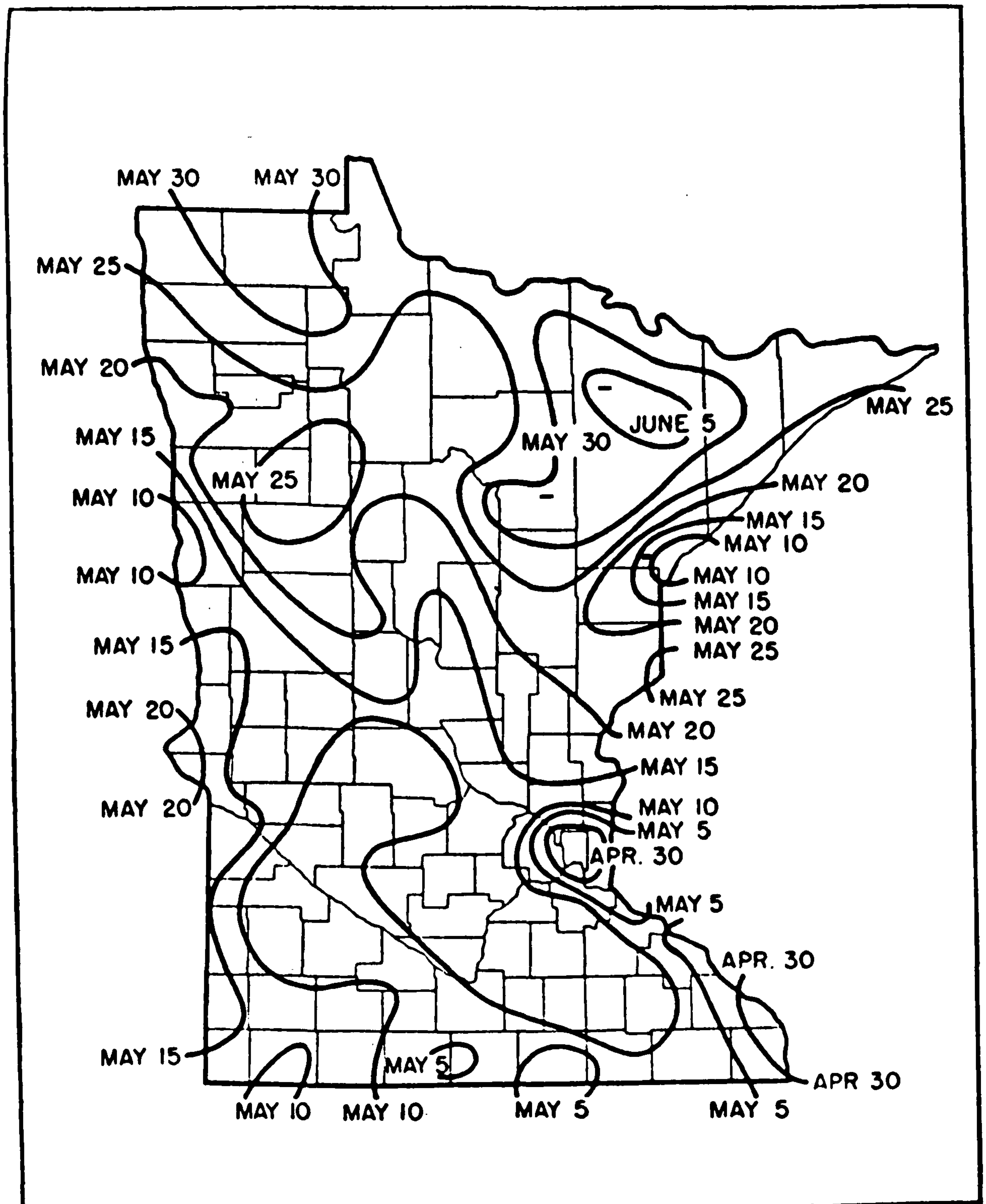

Figure 5. Location of Minnesota larch plantings observed for frost injury. Isotherms delineate dates of last killing frost in spring. A plus sign (+) indicates injury noted; a minus sign (-) indicates minor or no injury.

downslope. Barriers (trees, shrubs, elevated roads, topography, etc.) at right angles to the air flow produce cold air "dams" which are generally colder and more prone to frost than those areas on the downslope side where the cold air is free to flow and make room for warmer air from above.

FIELD TRIAL AND PLANTATION FROST DAMAGE AND RECOVERY EVALUATION

The rating systems described in Tables 2 and 3 were used this past year to evaluate damage to several plantings of larch. Two grafted European larch seed orchards were also rated.

Consolidated Papers Larch Trial V

One of the first indications that a damaging spring frost had occurred was the appearance of Larch Trial V near Argonne, Wisconsin. Trial V has a 4 replicate, 8 seed source, randomized block design that provided a good opportunity to evaluate both damage and subsequent recovery. Differences in needle and shoot browning were evident, and all materials were rated on June 18, 1986 for frost damage and on September 3, 1986 for recovery. Table 5 presents a summary of those frost ratings.

An analysis of variance indicated there were highly significant differences between seed sources for both damage and recovery. A control tamarack seed source (XLTK-5-80) provided an opportunity for comparison. The severity of the frost is evidenced by the average damage rating of 2.1 (11-25% brown needles) for the tamarack. The other seven seed sources were all rated above 4.0 (51-75% brown needles), although there were two sources (XLD-3-79 and XLD-5-79) that were less damaged than the remaining five seed sources.

An analysis of variance also indicated highly significant differences between seed sources in recovery from the spring damage. It is of particular note that two of the seed sources, XLD-3-79 and XLD-5-79, were not different from tamarack in their recovery. Three other seed sources, XLD-6-79, XLD-1-81, and XLD-LL-1-79, also recovered well. It is of interest that the remaining source of Japanese larch, XLL-1-79, was heavily damaged by frost and also had the poorest recovery rating of the eight sources tested.

Table 5. Consolidated Papers - Replicated Larch Trial V - spring frost damage and recovery summary.

		1986			
Material	Origin	Frost Damage Rating	Frost Recovery Rating	1985 Height	1986 Height
XLD-3-79	Sudeten	4.0[b]	1.3[e]	6.3	7.6
XLD-5-79	Czechoslovakia	4.2[b]	1.8[de]	5.0	6.4
XLD-6-79	Seed orchard	4.6[c]	2.1[cd]	3.6	4.0
XLL-1-79	W. German stand	5.0[c]	5.5[a]	1.6	1.0
*XLD-1-81	Sudeten	4.8[c]	2.2[cd]	3.6	4.0
*XLD-5-82	Sudeten	4.9[c]	4.6[b]	1.1	1.1
XLD-LL-1-79	Seed orchard	4.9[c]	2.7[c]	3.6	3.8
XLTK-5-80	Upper Michigan	2.1[a]	1.4[e]	4.7	5.2
**"F" test		S	S	S	S

*Planted as replacements for Japanese larch sources with high mortality - planted spring 1984.

**Analysis of variance "F" Test for treatments. "S" indicates values significant at the 5% level of probability.

[abcde]Duncan's New Multiple Range Test. Means followed by a common superscript are not significantly different.

Wisconsin Department of Natural Resources Larch Trial IX

An eight seed source, four replicate larch trial was planted the spring of 1984 near Boulder Junction, Wisconsin. Frost injury to the trial was noted the following spring and observations were recorded. The injury was light to moderate in the European larch and severe in the Japanese larch sources. The two hybrid sources had moderate to severe injury. Observations in August, 1985 indicated recovery was good for all sources with the exception of the Japanese larch.

Frost damage occurred again in the spring of 1986 and the trial was evaluated using the system described in Tables 2 and 3. The injury was more extensive than that of 1985 and resulted in considerable mortality as shown in Table 6. Two materials planted outside of the trial, XLL-7-81 and XLD-11-81, were also rated. Although an analysis of variance showed no differences between materials in degree of injury or recovery, there were differences in mortality. The two sources with the best survival, XLD-5-82 (seed orchard Sudeten origins) and XLD-11-81 (natural stand of *Larix polonica*), were again of Polish origin.

Table 6. Wisconsin DNR - Replicated Larch Trial IX - spring frost damage and recovery summary.

Material	Origin	1986 Frost Damage Rating	1986 Frost Recovery Rating	1985 Survival, %	1986 Survival, %
XLD-6-79	W. Germany	4.9	5.0	99	38
XLD-9-79	Wisconsin	5.0	5.7	88	17
XLD-5-82	Sudeten	4.8	5.0	97	49
XLD-6-82	Austria	5.0	5.1	99	28
XLL-1-79	W. Germany	5.0	5.9	85	5
XLL-6-79	Japan	5.0	6.0	82	0
XLD-LL-1-79	Seed orchard	5.0	5.3	89	28
XLL-LD-2-79	Seed orchard	4.8	5.3	99	36
*XLL-7-81	W. Germany	5.0	5.9	92	12
XLD-11-81	Poland	4.3	3.9	84	58

[a]Planted outside of trial.

Although the injury and subsequent mortality in this trial are unacceptable, the tendency of Sudeten and Polish seed sources to be among the most hardy European larch origins was again demonstrated. The severe impact of the 1986 frost injury on survival was due in part to the small size of the trees which were a result of poor soils and 1985 frost injury. Sandy soils tend to warm earlier in the spring, and the larch may have flushed earlier on this site than they would have on heavier soils in the same geographic area.

Wisconsin Department of Natural Resources European Larch Seed Orchard

Frost injury this past spring to a 20 clone European larch seed orchard planted in May 1985 was rated on June 17, 1986. The rating system used in evaluating the damage to replicated trials was also used in scoring for damage and recovery in seed orchards. Table 7 summarizes the injury and recovery ratings.

The average damage for all clones was 3.0 (26-50% of foliage and shoots damaged) with the worst clones rated above 4.0 (51-75% damage) and the least damaged rated less than 2.0 (11-25% damage). Recovery from the spring frost injury was evaluated on September 3, 1986. As would be expected, the least damaged clones were also among those clones with the best recovery. Not expected was the good recovery shown by several of the more severely damaged clones (orchard numbers 10, 14, 16, and 19). Their recovery was as good as the least damaged clones and continues to indicate that recovery evaluation is as important as damage evaluation.

Table 7. WDNR Summit Lake European larch frost injury and recovery ratings.

Frost Injury			Frost Recovery		
Orchard No.	Clone	Rating	Orchard No.	Clone	Rating
7	LD-6-81	1.5^{z}	4	LD-5-81	1.2^{w}
9	LD-19-80	1.6^{z}	14	LD-11-82	1.2^{w}
4	LD-5-81	2.0^{yz}	10	LD-13-82	1.4^{w}
17	LD-21-80	2.1^{xyz}	19	LD-16-82	1.4^{w}
3	LD-3-80	2.2^{xyz}	16	LD-14-80	1.5^{w}
6	LD-22-80	2.6^{wxy}	7	LD-6-81	1.5^{w}
1	LD-4-81	2.8^{vwxy}	9	LD-19-80	1.6^{wx}
10	LD-13-82	3.0^{uvwxy}	5	LD-1-80	1.6^{wx}
5	LD-1-80	3.1^{uvwxy}	15	LD-12-82	1.6^{wx}
16	LD-14-80	3.1^{uvwx}	6	LD-22-80	1.6^{wx}
18	LD-12-80	3.1^{uvwx}	11	LD-14-82	1.7^{wx}
11	LD-14-82	3.3^{tuvwx}	3	LD-3-80	1.8^{wxy}
13	LD-17-80	3.4^{tuvw}	17	LD-21-80	2.0^{wxy}
19	LD-16-82	3.4^{tuvw}	8	LD-3-82	2.0^{wxy}
15	LD-12-82	3.5^{tuvw}	1	LD-4-81	2.1^{wxy}
14	LD-11-82	3.8^{tuv}	13	LD-17-80	2.2^{wxy}
8	LD-3-82	4.1^{tu}	18	LD-12-80	2.2^{wxyz}
12	LD-1-81	4.2^{t}	2	LD-2-80	2.6^{xyz}
2	LD-2-80	4.3^{t}	12	LD-1-81	2.8^{yz}
20	LD-15-80	4.4^{t}	20	LD-15-80	3.2^{z}
*"F" Test treatment		S			S

*Analysis of variance "F" Test for treatments. "S" indicates values significant at the 5% level of probability.

^{tuvwxyz}Duncan's New Multiple Range Test was calculated when "F" test values for treatments were significant. Values followed by a common superscript letter are not significantly different.

COOPERATOR LARCH SEED ORCHARDS

STATUS OF PROJECT 3409 SEED ORCHARDS

Despite the problems that occurred with this past year's grafting, sufficient stock from previous years' grafting was available to plant part of a fourth European larch orchard. Two of the three orchards established earlier were injured by frost and the third is developing well. The frost injury discussed in a previous section of this report is of concern, and its effect on orchard establishment and early cone production will be closely observed.

The objective of the larch project continues to be the development of a long-term source of larch seed suitable for use in the Lake States and Northeast. The selection of clones to be used in the first orchards is based on provenance performance reported in the literature and from field trials initiated in the larch project. Sudeten and Polish sources continue to be the best performers and comprise the majority of the clones being included in the first orchards. It is recognized that these selections have not been progeny tested, but provenance information indicates that they will provide a better quality source of seed than is currently available on the open market. The current and future orchards could be improved by progeny testing, and indeed this is being proposed as the next step in the project.

Part of the rationale for initiating orchards prior to progeny testing was the belief that crosses could be made and clones evaluated as potential parent trees developed within orchards. This approach is also being advocated by the Genetics Unit of the Ontario Ministry of Natural Resources. By taking this approach, the time lag between testing and orchard establishment can be shortened considerably. Undesirable clones can be rogued from existing orchards as data are accumulated and new, more desirable clones can be incorporated into future orchards. All of the selections being used in the larch project are established at the IPC Greenville Nursery area. Many of the clones now being used in seed orchards are of an age and size in the Greenville arboretum that flowering is beginning and the first controlled pollinations can begin.

WISCONSIN DEPARTMENT OF NATURAL RESOURCES SEED ORCHARD

The Wisconsin DNR European larch seed orchard near Summit Lake, Wisconsin was one of two orchards planted the spring of 1985. The original orchard plan called for 20 clones and 20 ramets per clone, with the first half to be established in 1985 and the second half to be added in 1987. Orchard spacing was 30 feet within rows and 30 feet between rows. The grafts were staked and tied for support and wrapped with plastic tree protectors to prevent rodent damage. The orchard was mowed the first year and sprayed with Goal herbicide in an eight foot diameter circle around each graft. The orchard was not mowed the second year but glyphosate was sprayed around each graft to control vegetation.

Growth and survival were very good the first year but a late frost the following spring (May, 1986) damaged most of the clones in the orchard. A detailed discussion of the damage and recovery that occurred is given on page 24 of this report. Briefly, four of the five least damaged clones were Danish selections from a Polish larch seed source and the fifth was an IPC selection from a Sudeten larch planting in Northeast Iowa. Although the damage appeared to be severe, recovery during the growing season was very good. Figure 6 illustrates the appearance of the damaged clones and their recovery.

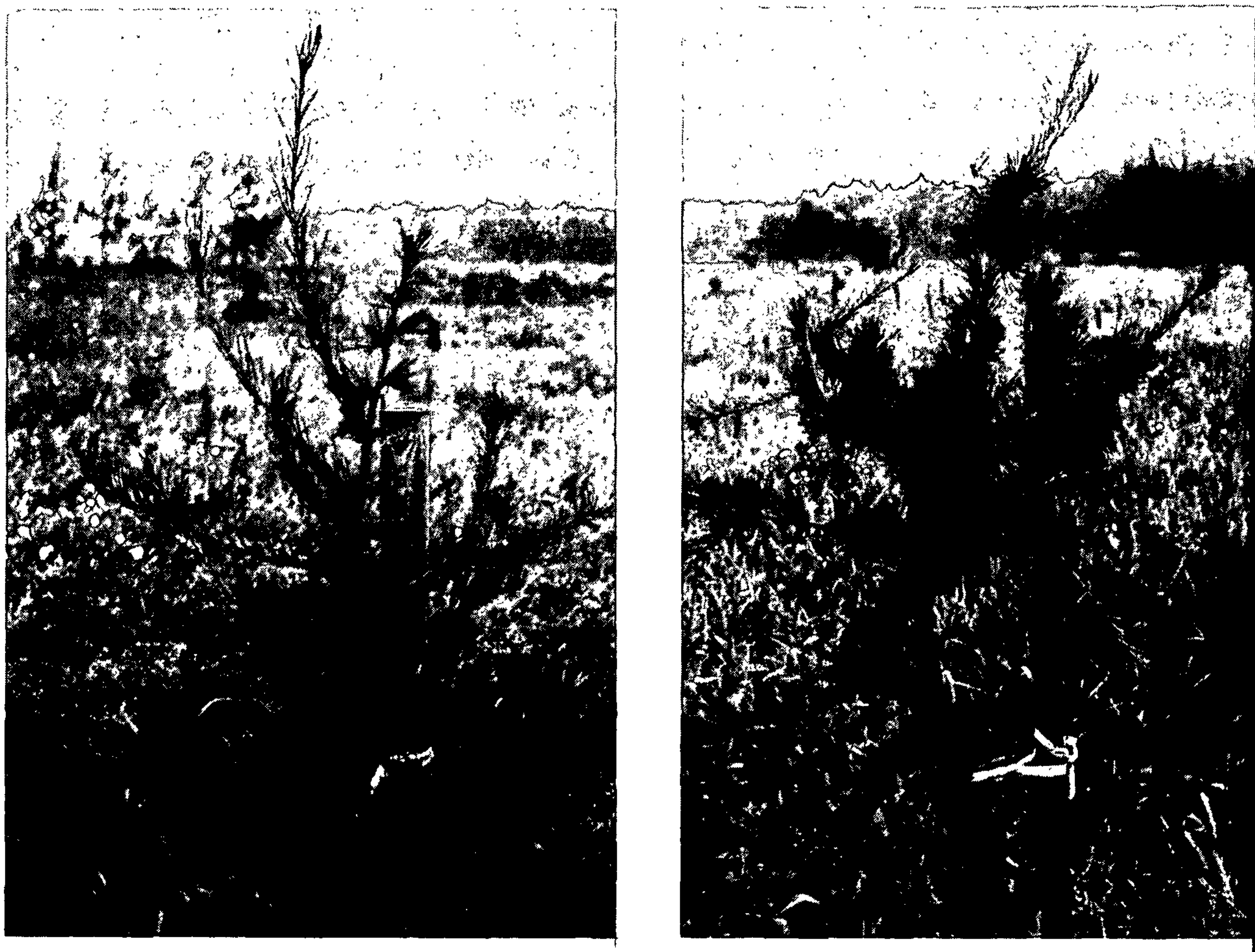

Figure 6. A late spring frost injured needles and shoots of European larch grafts in the Wisconsin DNR seed orchard near Summit Lake, Wisconsin. Recovery has been good for a majority of the clones. The grafts shown depict typical recovery.

Discussions with the Wisconsin DNR have led to the decision to establish the other half of the seed orchard on state lands in southern Wisconsin. There is concern that frost may impact seed production at the Summit Lake site. The frost damage that occurred this past spring, however, is considered unusual in that a warm period in early April had initiated an early dehardening process and set the plants up for greater than normal injury. It is believed that the impact, if any, of future frosts on cone and seed production will be confined to the lower portions of the crown within six to eight feet of the ground.

The orchard will be observed closely this coming spring for any further frost injury. Replacement of one dead graft and the addition of six grafts to fill vacant positions will be made. The orchard will also be fertilized and a herbicide will be applied if needed.

CONSOLIDATED PAPERS, INC. SEED ORCHARD

The second orchard established in 1985 was with Consolidated Papers near their greenhouse facilities in Monico, Wisconsin. The same 20 clones used in the Wisconsin DNR orchard were used in Consolidated's orchard.

The orchard site is on a level, somewhat elevated area surrounded on three sides by swamps. Initial concern was for frost incidence, but it was believed that the site was high enough and air drainage sufficient to prevent serious injury. Unfortunately, the choice for location was not a good one. Observations of the seed orchard on June 11, 1986 indicated widespread injury, and all clones and ramets were rated. Follow-up visits during the growing season showed little recovery from the spring damage, and it became apparent that an alternative site on which to relocate the orchard was needed. It was recommended that a site be selected from Consolidated lands as far south as possible. Clones will be grafted for establishment on a new site in the spring of 1988. The surviving grafts on the Monico orchard site will be observed for future frost incidence and growth.

MICHIGAN DEPARTMENT OF NATURAL RESOURCES SEED ORCHARD

The third European larch seed orchard was planted on July 10, 1985, using clones that had been grafted earlier in the spring. The orchard site is on a former nursery located in southeastern lower Michigan. Half of the orchard was planted the first year and part of the second half in July, 1986.

An existing irrigation system made it possible to establish first year grafts. Growth and survival have been very good due to vegetation control and fertilization. The frost problems associated with the previous two orchards did not occur in this one. The location of the orchard is well suited to existing facilities and available manpower. There is little doubt that this orchard will continue to develop well and will contribute considerable information to the project's use of larch seed orchards.

MEAD CORPORATION SEED ORCHARD

A fourth European larch seed orchard was planted on May 6, 1986 near Escanaba, Michigan on Mead Corporation lands. The site was an abandoned farm old-field that had a heavy quackgrass cover. The orchard location was sprayed with glyphosate the previous fall and disked just prior to planting. Planting positions were marked with stakes that served as supports for the grafts.

A total of 359 grafts were planted with a 16 gram slow-release fertilizer briquette (Woodace 14-3-3 with micronutrients) in the bottom of each planting hole. Grafts were tied to stakes for support and plastic rodent guards placed on each one. A prolonged dry spell occurred at the time of planting and a concentrated effort at watering was undertaken by Mead personnel over a 3-4 week period. The good growth and survival observed in late summer reflected the timely application of moisture. Figure 7 illustrates the appearance of one of the better individuals. Although some frost injury is anticipated, the influence of Lake Michigan should provide a moderating effect on spring temperature fluctuations and limit the effect of frost.

Figure 7. Growth of European larch grafts in Mead Corporation's seed orchard near Escanaba, Michigan, following planting this past spring was good despite a period of dry weather that necessitated watering.

SEED ORCHARD PLANS

Previously planted seed orchards will be brought to full stocking. Consolidated Paper's orchard will be relocated to an area in the central region of Wisconsin. The second half of the State of Wisconsin's orchard will be located in the southern part of Wisconsin. Grafts will be made for a hybrid larch seed orchard to be established by Scott Paper Company near Fairfield, Maine, the spring of 1988.

Existing orchards will continue to be closely observed for frost problems and growth and development will be monitored. As flowering information becomes available from the clones established in the IPC Greenville arboretum, any clone in current orchards that may not be flowering (receptive or shedding pollen) in synchrony with the other member clones will be removed and if feasible, replaced.

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REPLICATED FIELD TRIALS

CONSOLIDATED PAPERS, INC.

Larch Trial V is a four replication, randomized block design of eight larch seed sources planted in August, 1981, with container grown seedlings. The trial is on an old field near Argonne, Wisconsin and is considered to be a medium-quality hardwood site. Two Japanese larch sources were replaced in 1983 with European larch sources after mortality from repeated frost damage. Heavy vegetative competition from quack grass during the establishment phase of the planting slowed growth.

Spring frost injury coupled with a dry spring slowed growth for all materials during 1986. Mortality associated with frost occurred in the one remaining Japanese larch source, XLL-1-79. Two other Japanese larch sources were repeatedly injured by frost after the trial was planted and incurred early mortality. The frost damage rating given in Table 8 and discussed on page 21 shows the variation that exists between seed sources. An indication of the severity of this spring's frost is the amount of injury observed on the tamarack source, XLTK-5-80. Growth records indicate that spring frosts have repeatedly damaged the Japanese larch on this site, but it was not until this past spring that frost damage was severe enough to injure the other larch sources and to slow growth. Mortality from the 1986 frost occurred only in XLL-1-79 and in XLD-5-82, a replacement European larch source that never became established. Two European larch sources, XLD-3-79 and XLD-5-79, had recovery ratings that were not significantly different from the tamarack source (Table 5). Although growth was reduced, recovery from frost was good (Fig. 8) for most materials, and if normal spring conditions prevail this coming year continued recovery and growth is expected.

Table 8. Consolidated Papers replicated Larch Trial V.

	1984		1985		1986		
Material	Av. Ht., feet	Survival, %	Av. Ht., feet	Survival, %	Av. Ht., feet	Survival, %	Frost Damage
XLD-3-79	4.1	86	6.3	84	7.6^{w}	84^{x}	4.0^{y}
XLD-5-79	3.5	94	5.0	94	6.4^{wx}	89^{x}	4.2^{y}
XLD-6-79	2.5	66	3.6	64	4.0^{y}	61^{y}	4.6^{z}
XLL-1-79	1.6	64	1.6	46	1.0^{z}	19^{z}	5.0^{z}
XLD-LL-1-79	2.4	99	3.6	94	3.8^{y}	86^{x}	4.9^{z}
XLTK-5-80	3.5	96	4.7	91	5.2^{xy}	89^{x}	2.1^{x}
*XLD-1-81	2.6	99	3.6	96	4.0	96	4.8^{z}
*XLD-5-82	0.7	83	1.1	61	1.1	36	4.9^{z}

*Planted in 1983 as replacements for Japanese larch sources with high mortality. Other seed sources were planted in August, 1981.

^{wxyz}Duncan's New Multiple Range Test was calculated when "F" test values for treatments were significant. Values followed by a common superscript letter are not significantly different.

This planting has turned out to be an extremely valuable one. Even though growth after five years is not spectacular (Table 8), the planting demonstrates the potential and limitations of the use of late summer planted container stock where quack grass competition is heavy. Additionally, the frost prone nature of this site has provided the program with valuable information on variation between Japanese and European larch and differences among sources of European larch in frost resistance.

POTLATCH CORPORATION

Replicated Larch Trial VI was planted near Cloquet, Minnesota in June, 1982. The trial was a four replication, randomized block design testing eight seed sources. The area on which the trial was located was a conversion site that had been drum chopped in winter 1978-79 and planted with red pine in June, 1979. Heavy grass competition developed and the site was release sprayed with Roundup in August, 1980. Survival of the red pine was quite low and the area was disked in September, 1981, and scarified in April, 1982. The larch trial and several acres of hybrid larch around the trial were planted in June, 1982. Severe grass competition slowed development of the larch plantings and continued to reduce the survival of the residual red pine planting.

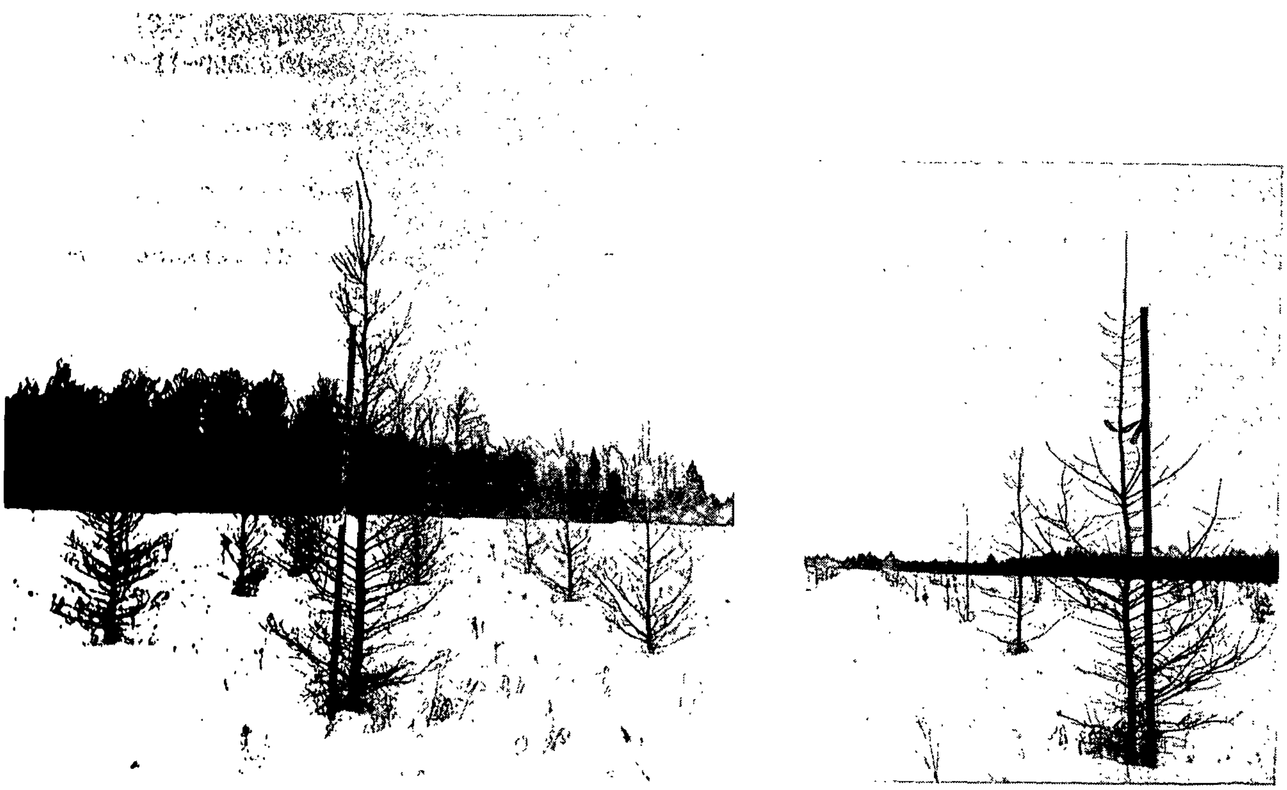

Figure 8. The seed orchard Sudeten larch source XLD-3-79 shown on the left consistently ranks among the best European larch seed sources for growth and survival. The tamarack seed source XLTK-5-80 shown on the right demonstrates the growth potential when planted on suitable upland sites. Both sources are in Consolidated Papers' replicated Larch Trial V in Northern Wisconsin.

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The larch stock was grown the winter of 1981-82 in Potlatch's greenhouse. Comments by nursery personnel and foresters indicated that they believed the slow establishment was due primarily to the condition of the stock when it was planted. It was the first larch stock they had grown, and it was quite succulent when outplanted. Little height growth occurred after planting, grass competition developed rapidly, and erosion was a problem on parts of the site. A summary of growth and survival after the second and fifth growing seasons is given in Table 9. The slow establishment is reflected in the low average heights of all materials after two years in the field. At the end of five years there were significant differences in height between materials with the hybrid source, Fig. 9, (XLD-LL-10-81), three European sources (XLD-6-79, XLD-11-81, and XLD-12-81), and one Japanese source (XLL-8-79) having the best growth. Although there were no significant differences in survival between seed sources, the analysis of variance F test was close to being significant for differences between blocks reflecting the nonuniformity of the site.

Table 9. Potlatch Corporation replicated Larch Trial VI.

	Spring, 1984		Fall, 1986	
Material	Av. Ht., feet	Survival, %	Av. Ht., feet	Survival, %
XLL-1-79	1.1	75	2.6^{z}	56
XLL-6-79	1.1	86	2.9^{yz}	59
XLL-8-79	1.1	82	3.8^{wxy}	56
XLD-6-79	1.5	77	4.2^{wx}	67
XLD-4-81	1.2	75	3.5^{xyz}	61
XLD-11-81	1.5	85	4.4^{wx}	70
XLD-12-81	1.3	78	3.9^{wxy}	59
XLD-LL-10-81	1.6	83	4.9^{w}	66

^{wxyz}Duncan's New Multiple Range Test was calculated when "F" test values for treatments were significant. Values followed by a common superscript letter are not significantly different.

Figure 9. The hybrid larch seed source XLD-LL-10-81 shown is in Potlatch Corporation's replicated Larch Trial VI near Cloquet, Minnesota. Although fifth year average height is less than expected, reflecting difficult establishment conditions, growth this past year was good.

No apparent frost damage has been noted with the exception of a few seedlings with very minor fall injury. The incidence of spring frost injury in Northern Minnesota larch plantings has been considerably less than that observed in Northern Wisconsin plantings.

The larch trial continues to have heavy vegetative competition from quack grass and aspen suckers. The red pine planted three years earlier is still beneath the same rank growth of grass that is affecting the growth of the larch, although it was interesting to note that most of the larch are now above the grass. If the typical pattern of larch growth occurs after it gets above the grass, extensive height growth should begin in this planting in 1987.

WISCONSIN DEPARTMENT OF NATURAL RESOURCES

The Wisconsin DNR replicated trial was established on the Northern Highland State Forest near Boulder Junction on May 14-16, 1984. The site was a jack pine plantation that had been clear cut the winter of 1983. Ground cover at the time of planting was composed of oak seedlings and stump sprouts, red maple sprouts, paper birch sprouts, hazel, blackberry, raspberry, bracken fern, wintergreen, blueberry, sweet fern, and scattered grasses. The site was prepared by a Brakke scarifier, but because of the desire to maintain uniform spacing the majority of the planting positions did not fall on the scarified strips.

Eight materials composed of 4 sources of European larch, 2 sources of Japanese larch and 2 sources of hybrid larch were planted. Two additional sources of larch were planted outside of the trial. Table 10 presents growth and survival data for the three years following planting. The effect of the frost damage described on page 22 is evident. The Japanese larch sources, XLL-1-79, XLL-6-79, and XLL-7-81, sustained the highest mortality. The least damaged sources were two European larch materials, XLD-5-82 and XLD-11-81, both of which are Sudeten origins. The small size and poor physiological condition of the trees in the spring of 1986 contributed to the excessive frost damage and poor recovery at this planting. The size and condition of the stock are in part a function of the site. Sandy soils warm up early in the spring and increase the severity of late spring frosts. Sandy soils also result in reduced growth rates and longer establishment times.

Although the trial was severely damaged, it provided a graphic example of the variation between seed sources. Because of that variation within *Larix*, it should be possible to select for adapted sources and to breed for greater resistance to frost injury.

The foresters have agreed to let the trial remain in its present state of low survival for the observation of future growth or injury.

Table 10. Wisconsin Department of Natural Resources - replicated Larch Trial IX.

Material	1984 Av. Ht., feet	1984 Survival, %	1985 Av. Ht., feet	1985 Survival, %	1986 Av. Ht., feet	1986 Survival, %	1986 Frost Damage
XLD-6-79	1.5	99	1.7	99	1.5	38	4.9
XLD-9-79	1.4	88	1.6	88	2.0	17	5.0
XLD-5-82	1.8	97	2.2	97	1.9	49	4.8
XLD-6-82	1.8	99	2.1	99	1.8	28	5.0
XLL-1-79	1.5	96	1.2	85	0.6	5	5.0
XLL-6-79	1.6	99	1.3	82	--	0	5.0
XLD-LL-1-79	1.4	93	1.9	89	1.7	28	5.0
XLL-LD-2-79	2.1	100	2.6	99	2.7	36	4.8
*XLL-7-81	1.4	100	1.1	92	2.6	12	5.0
*XLD-11-81	1.5	89	2.0	84	2.0	58	4.3

*Extra stock planted outside of trial.

MICHIGAN DEPARTMENT OF NATURAL RESOURCES

An eight seed source replicated larch trial was planted on May 14-15, 1986, on state land near Gaylord, Michigan. The site was an old-field (associated with an abandoned homestead) with a ground cover of lichen, scattered grass, bracken fern, and scattered choke cherry. A red pine plantation on the north end of the trial indicated a site index of about 60. The soil classification is believed to be either a Rubicon or Kalkaska series.

The trial was hand planted with each position scalped free of vegetation. Soil moisture at the time of planting was approximately 10% of field capacity. The soil was so dry that there was concern for survival. The State of Michigan foresters involved concurred and approximately 1 to 1-1/2 gallons of water was applied to each tree within one day of planting, using a fire control tank truck and two men with pails. Several days after planting, 1-1/2 inches of rain fell. Another concern that arose during planting was the extremely high numbers of white grubs and cutworms that were found, 4-6 larvae per shovel full of soil. Recommendations were to treat each tree with diazanon to control the inevitable root damage by the beetle larvae.

Several sources of planting stock (XLD-3-84, XLD-LL-1-79, XLD-6-79, and XLD-1-81) had yellow needles that had flushed to a length of approximately one half inch. The remaining stock was dormant. The trial had been scheduled for measurement in the fall but time and budget restrictions did not allow it. The trial will be observed this coming spring and evaluated for growth, survival, and possible frost injury - the site is in a known late spring frost area.

MEAD CORPORATION

Two replicated provenance trials testing 23 larch seedlots were planted by Mead Corporation this past spring on two sites. The seed was provided by Project 3409, and the stock was grown by Mead in their greenhouses in Escanaba, Michigan. Both plantings were on old field sites with heavy grass competition. One of the planting sites (Sawyer Farm) was sprayed with 2.5 quarts of Roundup per acre in the summer of 1985 and disked in late fall. The area was again sprayed with Roundup at two quarts per acre in early May, 1986, just prior to planting. Returning competition was controlled by treatment of a three to four foot circle around each tree. The trees were watered during a dry period following planting.

The Sawyer Farm site was the location of one of the first container larch plantings put in as part of Project 3409 in 1981. The planting failed after initial high survival and good growth. Rodents, primarily voles, traveled the scalped furrows beneath cover that developed from a rank growth of quack grass that collapsed into the furrows from snow weight. Virtually every seedling in an approximately 10 acre planting was girdled by rodents. It was this past experience with grass competition and rodents that led to the intense effort to control vegetation during the establishment of the provenance trial at the same location.

A second provenance trial with the same seed sources was also planted this spring on Mead's Virgil Wright site. This site had been planted previously with two replicated trials that failed from drought stress.

The Virgil Wright area is an old-field site with a sandier texture than the Sawyer Farm site. The soils are also shallow, being underlain at about 20 inches with limestone bedrock. The site was prepared for planting by furrowing and band spraying with Oust along the tops of the furrows. The appearance of the planting when visited in September seemed to indicate damage had occurred from the Oust herbicide treatment. A number of rows had seedlings with a chlorotic, stunted appearance. There was speculation that rainfall had moved Oust into the furrows, and the effective herbicide rate near the seedlings was higher than the target rate of 3 ounces per acre.

The trials were not measured this past fall, but observations will be made this coming spring and measurements will be made next fall.

DEMONSTRATION FIELD PLANTINGS

THILMANY PULP AND PAPER COMPANY

Four, one-acre Japanese larch plantings were put in by Thilmany's tree farm cooperators in the Waupaca, Wisconsin, area. Two of the four plantings have been established and two have failed because of excessive grass competition.

The best planting of the two that are established is near Big Falls, Wisconsin, on a site with a loamy sand soil texture and a water table at three to four feet. Table 11 presents height and survival data for age 4 and 5. The tallest individuals were over 15 feet with diameters greater than 2 inches b.h. (Fig. 10).

Table 11. Thilmany Pulp and Paper Company 5-year-old Japanese larch plantings.

	1985		1986	
	Av. Height, feet	Survival, %	Av. Height, feet	Survival, %
BIG FALLS	6.0	86	9.1	79
WAUPACA	5.0	42	7.5	42

The second planting, near Waupaca, was on a farm field that had been abandoned for two years prior to planting. The ground cover was grass and no site preparation was done prior to planting. Grass competition was treated with glyphosate in a wick applicator after planting, and some damage and mortality did occur. However, the low survival shown in Table 11 was due primarily to standing water and a high water table in the southeast portion of the trial. The water was not present at the time of planting.

Figure 10. At the end of the fifth growing season the Japanese larch seed orchard source XLL-3-79 growing on a Thilmany Pulp and Paper Company tree farm cooperator's site near Big Falls, Wisconsin, is averaging over 9 feet in height with the best individuals over 15 feet. Japanese larch appears to be adapted to the southern half of Wisconsin, where the incidence of late spring frosts is limited.

The tallest individuals are over 13 feet in height and greater than 1.5 inches dbh. Deer browsing has occurred, but injury has been minor. Damage has occurred from buck rubbing. The mortality in this planting demonstrates the effect of poor drainage/aeration on Japanese larch. A minor incidence of fall frost damage was noted. However, the frost injury that was so apparent this past spring in the northern areas of Wisconsin and Michigan was not noted in these plantings. The good growth and minor frost injury in both of these plantings indicates that additional plantings of both hybrid and Japanese larch should be established on similar sites and latitudes for further evaluation.

MEAD CORPORATION

A small planting of tamarack and European larch was put in on May 12-16, 1980, by Mead Corporation on an old-field site near Shingleton, Michigan, in the Upper Peninsula. The records indicate there were 5200 European larch and 1000 tamarack planted, but only the 1000 tamarack and 1100 larch were found. White spruce and red pine had also been planted but were not measured. The origins of the larch and tamarack are not known.

Table 12 presents field measurements taken on a block of 10 rows of larch and tamarack on the Shingleton site. Survival was high for both species, but average height growth was considerably less than would be expected for either species at age seven. Grass competition was severe and probably accounts for the low average height growth. The tallest trees in both species were over 10 feet. There was evidence of snow damage, a problem that was noted in a 1976 IPC/WDNR hybrid aspen planting several miles to the north.

Table 12. Mead Corporation Shingleton larch and tamarack planting - 7-year growth and survival.

Row No.	Species	Av. Height, feet	Survival, %	Av. Frost Damage Rating
1	*L. decidua*	4.0	80	1.6
2	*L. decidua*	4.2	96	2.0
3	*L. decidua*	4.7	91	2.2
4	*L. decidua*	4.3	89	1.8
5	*L. decidua*	4.3	96	1.9
6	*L. decidua*	4.6	87	1.5
7	*L. laricina*	5.6	81	1.0
8	*L. laricina*	7.4	89	0
9	*L. laricina*	7.7	89	0
10	*L. laricina*	5.3	82	0

There was evidence of fall frost injury to the European larch at the time of measuring on October 8, 1986. The damage was recorded on 48% of the European larch, with no injury to the tamarack. The average frost damage rating was 1.8, which corresponds to less than 25% of the needles and shoots injured. There was no evidence of injury from spring frosts.

Cones were noted on 7% of the tamarack, but none were found on the European larch. The early flowering of tamarack is not unusual, and the observation of cones in this planting at age seven supports numerous reports in the literature of precocious flowering.

HERBICIDES AND LARCH

LORETTA CHEMICAL SITE PREPARATION TRIAL - CONSOLIDATED PAPERS

The sensitivity of larch to hardwood release herbicides led us to evaluate the potential of using site preparation chemicals to eliminate potential hardwood competition prior to planting and the possible effects of chemical persistence on planted larch. A medium quality hardwood site in Northern Wisconsin on Consolidated Papers lands near the town of Loretta was chosen for the trial.

The site had been harvested during May-July, 1984, and brush raked in July. A three replication, randomized block design trial was superimposed on the site, and there were large areas of exposed soil throughout the trial. Four chemicals were chosen for testing, and the treatments and application dates are given in Table 13. Two soil samples were taken and the texture and nutrient analyses are given in Tables 14 and 15.

Table 13. Loretta chemical site preparation trial treatments.

Treatment	Rate	Application Method	Treatment Date
Velpar liquid	3 qts/acre	Broadcast	May 22, 1985
Velpar liquid	3 qts/acre	Solid stream	May 23, 1985
Oust-preemergent	3 oz/acre	Broadcast	May 7, 1985
Oust-postemergent	3 oz/acre	Broadcast	May 22, 1985
Arsenal	3/4 lb/acre	Broadcast	Aug. 5, 1985
Arsenal	1 lb/acre	Broadcast	Aug. 5, 1985
Garlon 4	4 qts/acre	Broadcast	May 23, 1985
Control	No treatment		

Table 14. Soil texture analysis for Loretta herbicide trial.

Sample Number	Sample Depth, inches	Sand, %	Silt, %	Clay, %	Texture Class
1 (northwest corner)	0-6	50.2	38.7	11.1	Loam
	6-12	53.2	37.2	9.6	Sandy loam
	12-18	53.2	38.2	8.6	Sandy loam
2 (east side)	0-6	56.4	33.2	10.4	Sandy loam
	6-12	44.0	44.4	11.6	Loam
	12-18	56.0	34.4	9.6	Sandy loam

Table 15. Soil nutrient analysis for Loretta herbicide trial.

Sample Number	Sample Depth, inches	pH	Organic Matter, tons/acre	lb/acre				
				N	P	K	Ca	Mg
1	0-6	5.1	39	2786	300	150	1000	110
	6-12	5.0	11	786	220	150	550	40
	12-18	5.1	5	357	54	80	750	40
2	0-6	5.6	47	3357	300	160	2000	260
	6-12	6.0	17	1214	270	105	1800	100
	12-18	6.0	5	357	135	70	1700	60

The treatments were applied the spring and summer of 1985 and seedlings were hand planted the spring of 1986. A vegetation analysis was undertaken on July 16-17, 1986, approximately one year after treatment. Table 16 presents a description of the ground cover present. The amount of area occupied by the various plant components was determined by measuring the actual space occupied by each component within a four foot wide east-west transect through the center of each plot and expressing the presence as a percent of the total transect area.

Table 16. Vegetation present one year after herbicide treatment.

Treatment	% of Surface Area					
	Grass	Forbs	Woody	Open	Sedge**	Brambles**
Velpar L Broadcast	8^{c}	27^{cd}	13^{abc}	43^{a}	2^{ab}	2
Velpar L Solid str.	22^{b}	34^{bc}	19^{a}	7^{c}	9^{a}	6
Oust pre	3^{c}	49^{ab}	6^{bcd}	38^{ab}	3^{ab}	0
Oust post	0^{c}	54^{a}	16^{ab}	23^{bc}	5^{ab}	+
Arsenal 3/4 lb	2^{c}	35^{bc}	1^{cd}	53^{a}	1^{b}	2
Arsenal 1 lb	8^{c}	34^{bc}	0^{d}	54^{a}	$+^{b}$	3
Garlon	49^{a}	29^{cd}	1^{cd}	15^{c}	$+^{b}$	0
Control	32^{ab}	30^{cd}	10^{abcd}	22^{bc}	$+^{b}$	2
*"F" Test for treatment	S	S	S	S	S	NS

*Analysis of variance "F" Test for treatments. "S" indicates values significant at the 5% level of probability, "NS" - nonsignificant test.

**A plus sign (+) indicates a minor presence, usually represented by only a single plant.

abcdDuncan's New Multiple Range Test. Means within a column followed by a common superscript are not significantly different.

There were significant differences due to treatments in five of the six plant categories present and in the amount of open area present. It is apparent from Table 16 that all treatments with the exception of Garlon and the Velpar band treatments were significantly different from the untreated control in controlling grass. The presence of forbs was greatest on the Oust treatments, due primarily to the large numbers of bull thistle and climbing false buckwheat. The presence of these two species on the Oust plots was so extensive that it was possible to identify the Oust plots without a diagram.

The target species for this trial were woody plants. Unfortunately, the variation in numbers of woody plants between control plots was considerable, apparently due to the mechanical site preparation that occurred prior to the placement of the trial. Differences between the control plots and the best treatments, Arsenal and Garlon, which had the lowest amount of woody vegetation after treatment, could not be detected statistically. However, when the amount of open area on the Arsenal plots after one year is considered, there is reason to believe that the two rates used effectively controlled vegetative competition. In all Arsenal analyses there were no differences between the 3/4-pound and 1-pound rates. The Velpar liquid broadcast treatment was also quite effective in controlling vegetation as shown by the amount of open area remaining on the plots.

Bareroot and container hybrid larch, container red pine, and bareroot hybrid aspen were planted in the trial the spring of 1986. The seedlings were measured this past fall, and height and survival information is given in Table 17. The container larch apparently did not overwinter well prior to planting, and growth and survival were minimal in all treatments plus the control. Those data were, therefore, not included in the measurements.

The bareroot larch had the highest survival and best growth, followed by the hybrid aspen. The red pine did not appear to have much shoot elongation following planting; the survival figures may be misleading due to the difficulty of locating the seedlings among the vegetation, and those seedlings recorded as missing may have been present. Herbicide injury was not detected on any of the planted seedlings. An analysis of variance was run on growth and survival for the bareroot larch, and there were no significant differences due to treatment.

Table 17. Loretta herbicide trial first year seedling height and survival.

Treatment	Bareroot Larch Av. Ht., feet	Bareroot Larch Survival, %	Hybrid Aspen Av. Ht., feet	Hybrid Aspen Survival, %	Container Red Pine Av. Ht., feet	Container Red Pine Survival, %
Velpar L	1.6	100	1.8	73	0.5	53
Velpar L	1.3	87	1.8	93	0.5	40
Oust pre	1.4	97	1.7	100	0.5	60
Oust post	1.8	100	1.4	73	0.5	60
Arsenal	1.3	97	1.5	60	0.6	80
Arsenal	1.4	80	1.4	70	0.4	67
Garlon	1.6	83	1.8	40	0.7	33
Control	1.3	79	1.4	87	0.5	47

The trial will be evaluated for both returning vegetation and the growth and survival of the seedlings. Although no injury was noted, growth may be retarded and measurements over the next two growing seasons should reveal herbicide effects and provide more reliable data for analysis.

KRAFT PULPING CHARACTERISTICS OF PLANTATION-GROWN RED PINE - WITH COMPARISON TO JACK PINE, EUROPEAN LARCH, AND HYBRID LARCH

SUMMARY

Kappa 50 and kappa 30 pulps were prepared from bark-free chips of 24-year-old (thinnings) and 49-year-old (mature wood) red pine. The resulting pulps were evaluated for strength and compared with earlier evaluated jack pine control pulps and pulps from European, Japanese, and hybrid larch. Of particular interest was the usefulness of thinnings from red pine plantations as a conifer fiber source. The red pine thinnings pulped at a similar rate as the mature red pine chips, but both sources pulped with greater ease than the jack pine control chips and wood from the three sources of larch. Pulp yields for red pine thinnings were 2 to 3% lower than for the mature red pine chips and 2 to 3% lower than European and hybrid larch.

Regarding strength properties, pulps from red pine thinnings developed adequate breaking length but at a breaking length of 10 km had 32% lower tear, 13% lower burst, and 20% lower tensile energy absorption in comparison with pulps from 18-year-old European larch plantation-grown trees.

INTRODUCTION

Extensive planting of red pine began in the late 1950s, and red pine continues to be the most widely planted tree species in the Lake States Region (23.7 million trees produced in State Nurseries in 1985). Thinnings from the earliest plantings are becoming increasingly available as a conifer fiber source. Little has been published on the pulping characteristics of red pine, and red pine pulps are expected to be the standard of comparison for other conifer species recommended for use in the Lake States and the Northeast. The purpose of this study is to (1) obtain wood quality and pulping information on pulpwood-sized red pine thinnings, (2) compare pulp and wood quality information on thinnings with information on mature red pine wood, and (3) evaluate the potential of using 18- to 25-year-old larch species and larch hybrids as a replacement for red pine.

Earlier mill experience and Project 3409 measurements of wood specific gravity suggest red pine thinnings that are high in juvenile wood will yield less pulp per cord and produce pulps with lower tearing strength than comparable-aged larch species.

MATERIALS AND METHODS

Wood Properties

The trees selected for this study consisted of five 24-year-old pulpwood-sized trees from a plantation scheduled for thinning in the summer of 1986 (designated as thinnings) and three crop trees from a managed 49-year-old red and white pine plantation (designated as mature wood). The plantations are located in east central Wisconsin and are typical of plantings in that area.

The size of the experimental trees, along with information on wood specific gravity, and percent bark, heartwood, compression wood, and juvenile wood are summarized in Table 18. After collection, the trees were sampled by taking disks at the base, 4 1/2 feet (1.37 m) and every 6 ft (1.83 m) to a 4-inch (10.2 cm) top outside diameter. The bolts were then debarked and chipped. Chips were screened prior to pulping, and fractions passing the one inch (25.4 mm) screen but retained on the 1/2- and 1/4-inch (12.7 and 6.4 mm) screens were pulped. Oversize reject chips were rechipped once and rescreened

Table 18. Tree size and wood quality data.

Type of Material	Av. dbh, inches	Av. Total Height, ft	Av. Whole Tree sp. gr.	Bark, %	Heart-wood, %	Juvenile Wood, %	Compression Wood, %
Red pine thinnings	6.1	36.7	0.32	10.2	11.2	82	4.0
Red pine mature wood	10.5	57.3	0.39[a]	7.8	16.9[a]	25[a]	6.6[a]

[a]Values based upon lower 18 foot section of the tree, i.e., the wood sample that was used in pulping study. Values to a 4-inch top are 0.36, 13, 42, and 4%, respectively.

prior to discarding the rejects and fines. The accepted chips were air dried prior to pulping.

Pulps were evaluated for their usefulness as bag papers by kraft cooking to a kappa number of approximately 50 and for use as part of a furnish of bleachable-grade pulps by cooking to a kappa 30. The pulping conditions used were the same as for earlier studies conducted by Project 3409 on European larch, Japanese larch, and European x Japanese hybrid larch pulpwood-sized thinnings. Fifty-five-year-old jack pine wood was also included in the earlier studies as a control pulp.

The data on percent bark are the weighted average values and were estimated from disk samples by removing the bark and comparing wood and bark oven-dry weights. Tree specific gravity is the dry weight divided by green volume, with the green volume being determined by a maximum-moisture, water-displacement procedure using disks located at six-foot intervals up the tree to a four-inch top diameter. Compression wood and heartwood levels were determined using disk samples taken at six-foot intervals. Moist disks were examined using a light box to help distinguish heartwood and compression wood areas. Juvenile wood values were determined by examining the disks of the trees involved and determining the annual ring where the transition between juvenile and mature wood occurred (based upon the presence of a normal springwood/summerwood ratio). Annual ring 13 was the location where the transition most often occurred and was the ring used in most instances to determine the percent juvenile wood. The levels presented are weighted average whole-tree values to a four-inch top diameter for the thinnings and weighted average values for the lower 18 feet (5.5 m) for the mature wood samples. Weighted average values to four-inch top are also available for the mature wood trees (see the footnote in Table 18).

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Pulping and Bleaching Conditions

The chips from the several trees representing each of the two types of red pine wood (thinnings and mature wood) were thoroughly mixed and air dried prior to pulping. Pulping runs were carried out in a M&K digester using the cooking conditions given in Table 19 to obtain kappa numbers in the 28 to 32 and 47 to 53 range (kappa 30 and 50 pulps). The cooking liquors were prepared from solutions of sodium hydroxide and sodium sulfide of known concentration and density, together with the appropriate amount of dilution water. A microcomputer was used to control the system and acquire temperature, H-factor, and conductivity data. Spent liquor samples were taken to determine the residual alkali. Kappa number, yield, viscosity, and brightness were measured on the pulps produced.

Table 19. Pulping conditions.

Wood charge, kg o.d.	4.0
Water-to-wood ratio, cm^2/g	4.0
Effective alkali, % o.d. wood	16.0
Sulfidity, %	25.0
Ramp rate, °C/min	1.8
Pulping temperature, °C	172.0
H-factors	860-1375

The chips were fiberized in a Williams disintegrator, and the pulp was screened through a 0.006-inch (0.15 mm) cut screen plate in a small Valley flat screen. The rejects were oven dried, weighed, and discarded. The accepted fiber was then used to determine the physical properties of the pulps using TAPPI methods after beating in a PFI mill at 10% consistency. Handsheets were prepared from the kappa 30 and kappa 50 pulps after beating in the PFI mill to CSF freeness intervals of 650, 600, 525, 450, and 350. Handsheets were evaluated for burst, tear, tensile, TEA, stretch, porosity, scattering coefficient, and adsorption coefficient.

Two 50-gram samples of the kappa 30 pulp were bleached using a (C/d)EHDED sequence. Chlorination was carried out in a stirred tank reactor. The E, H, and D stages were carried out in plastic bags immersed in a constant temperature bath. Kappa number was measured after the E1 stage. Viscosity, brightness, and pH were measured on pulps from each bleaching stage. The results of the bleaching investigations will be reported in a later progress report.

RESULTS AND DISCUSSION

Wood Properties

The trees within each age class (24 *vs.* 49 years) were uniform in size and wood quality (Table 18). All were straight, dominant and codominant trees and, as a result, had similar levels of compression wood. The thinnings, however, had much more juvenile wood (82 *vs.* 25%), less heartwood, and 18% lower specific gravity (0.32 *vs.* 0.39).

The low specific gravity of red pine thinnings and their higher levels of juvenile wood appear to be the principal wood quality disadvantages associated with the use of thinnings. The low specific gravity values reported confirm earlier values for young red pine published by Cody[5] and Rees and Brown.[6] The most economical use of the mature trees evaluated in this study would be to use the lower 18 to 20 feet (5.5 to 6.1 m) of the trees for box bolts and the tops for pulpwood. The tops are expected to have specific gravity, pulping, and pulp strength characteristics very similar to those of the thinnings described in this study.

Table 20 summarizes the characteristics of the chips used in this study. Rejects (Table 3) are chips retained on the one-inch screen after one rechipping. Prior to pulping, the chips were air-dried. Moisture contents (Table 3) were taken after chipping and prior to air-drying. The chip size distribution for the two sources of wood was very similar and, as might be expected because of the higher levels of heartwood and lower juvenile wood, the mature wood chips were lower in moisture content.

Table 20. Characteristics of chips prepared for pulping.

Wood Sample	Percent of Chips on Each Screen[a] On 1/4-inch	On 1/2-inch	Fines	Rejects[b]	Moisture Content,[c] %
24-year-old thinnings	18.3	74.8	4.4	2.4	62
49-year-old mature wood	20.2	73.7	3.9	2.3	58

[a] Based upon ovendry weight measurements.
[b] Rejects from first screening were rechipped once and rescreened.
[c] Moisture content of on 1/4- and on 1/2-inch chips, determined on a fresh weight basis.

Pulping Characteristics

The pulping times required to produce kappa no. 50 (bag paper) and kappa no. 30 (bleachable grade) pulps were established and then used to obtain pulps that could be used in pulp strength comparisons. Table 21 summarizes the results of varying pulping conditions on kappa number and pulp yield. Pulping time has been replaced by the generally more useful H-factor.[7] Differences between the two sources of chips were further contrasted by plotting kappa number *vs.* H-factor, as illustrated in Fig. 11.

Table 21. Pulping conditions, kappa number, and pulp yield.

Material	H-Factor	Kappa Number	Unscreened Yield, % o.d. wood	Screened Yield, % o.d. wood	Screened Rejects, % o.d. wood
Thinnings	706	58.7	48.8	48.8	0.0
	867	51.5	47.6	46.6	1.0
	1394	29.6	45.4	44.6	0.8
	1600	23.6	44.4	44.4	0.0
	2013	22.2	43.8	43.8	0.0
Mature wood	851	48.3	49.2	48.6	0.6
	911	45.9	49.2	49.2	0.0
	1352	31.8	48.8	48.3	0.5
	1692	24.9	47.4	47.4	0.0

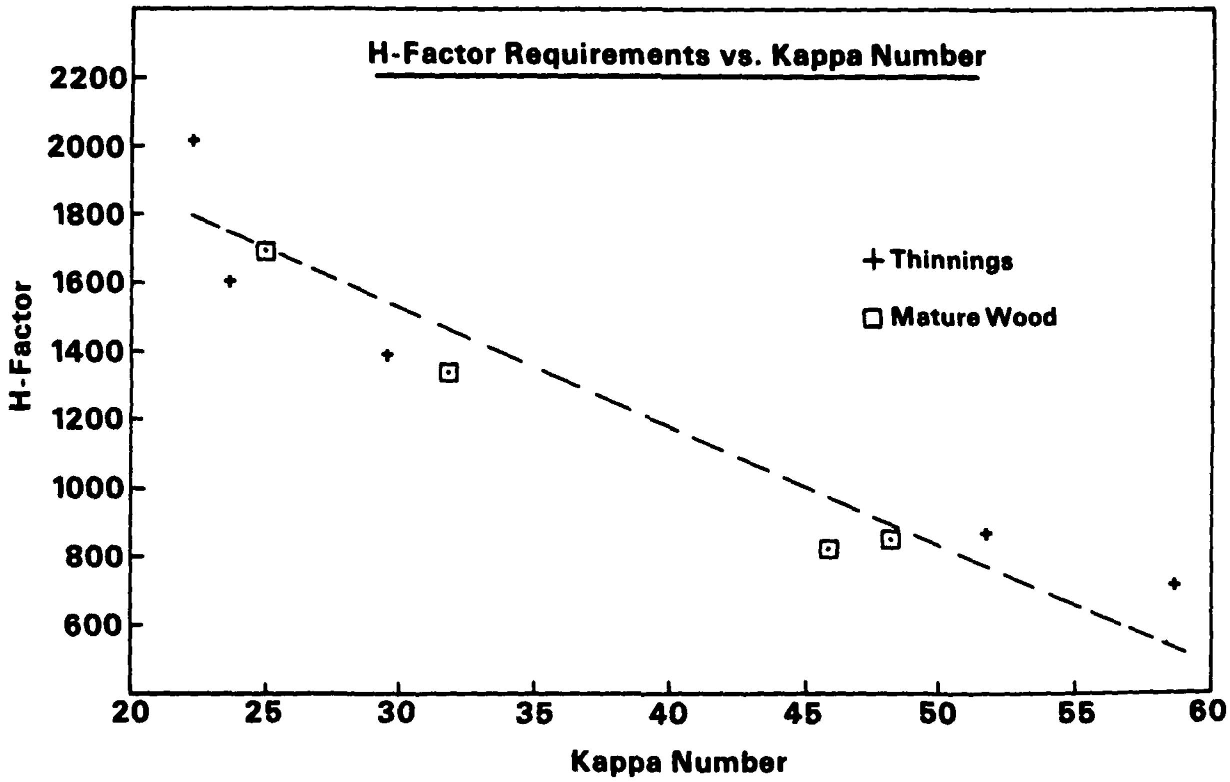

Figure 11. H-factor requirements *vs.* kappa number for red pine. The regression line is based upon the equation y = 74.18 + (-0.0291 • H-factor).

Multiple regression analyses were used to compare the pulping rates of the chips from the red pine thinnings with chips from the mature wood. As can be seen from the regression line (Fig. 11) differences in pulping rates were minor. However, the overall rate of pulping for red pine, as will be commented on later, was much more rapid than for larch and jack pine.

Obtaining the maximum yield of pulp per oven dry pound of wood is extremely important. Figure 12 illustrates the differences in pulp yield that were evident when the two sources of wood were evaluated at comparable kappa numbers. Mature wood yield was approximately 2% greater at kappa 50 and 3% greater at kappa 30. The degree of polymerization of the pulps, as indicated by Cuene viscosity measurements, was about 4 to 6 units higher for the mature wood pulps, and indicates a lower level of carbohydrate degradation during pulping. This is not unexpected because of the higher juvenile wood content of the thinnings. Levels of screen rejects were somewhat variable but apparently not influenced by wood source. Rejects were 1% or less, even for the pulps cooked to the higher kappa numbers (46 to 59).

Pulp Strength

The strength properties of the pulps obtained from red pine thinnings and mature red pine chips are summarized in Table 22. Conifer pulps are refined to improve formation, increase bonding, and to improve tensile strength (breaking length). Such refining increases sheet density, breaking length, and bursting strength and decreases tear strength.

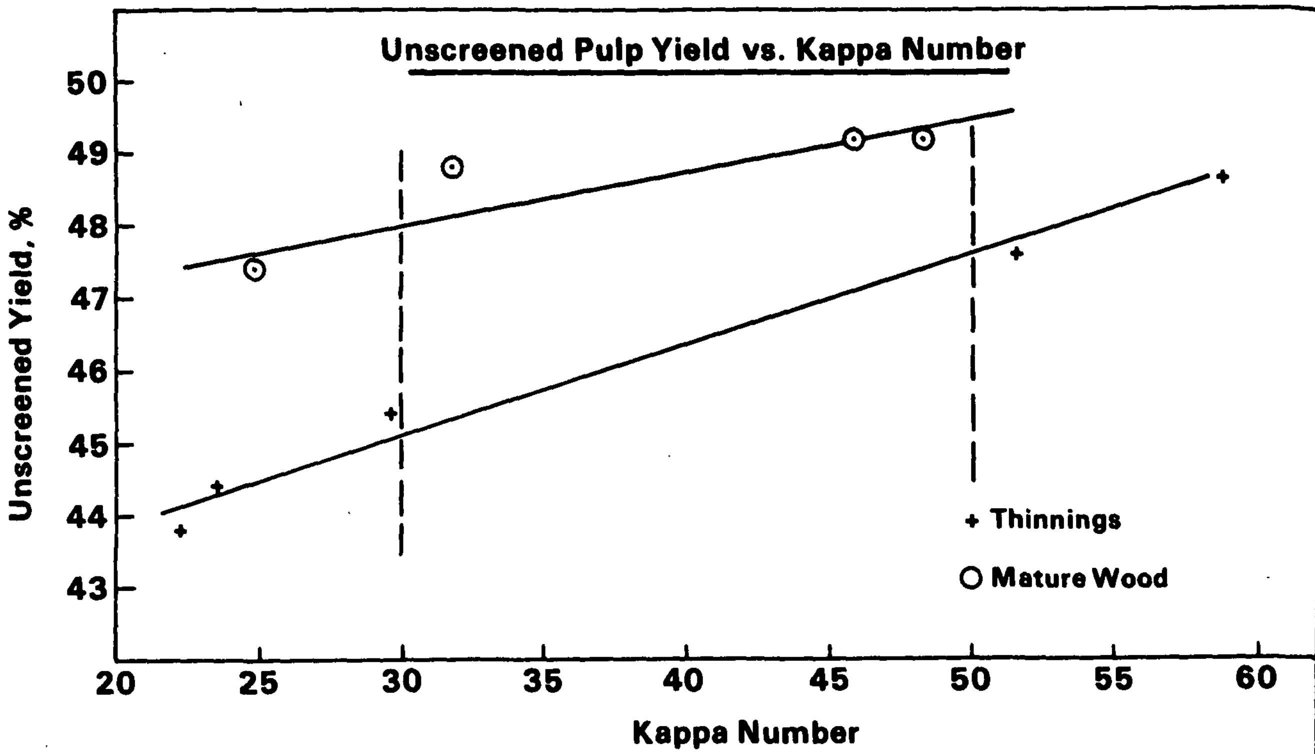

Figure 12. The influence of kappa number on unscreened pulp yield from red pine thinnings and mature wood.

One extremely useful way of evaluating two pulps is to compare them at a constant sheet density. When this is done, approximately the same amount of fiber and the same level of bonding is involved in making the evaluation. When such a comparison was made using the tear factor data generated, the values for the kappa 30 and kappa 50 pulps were very similar in magnitude and for this reason were combined when comparing the two sources of pulp. Figure 13 is a plot of the combined data, and as this comparison indicates, the mature wood pulp had a greater tearing strength. The differences range from 30% greater (15 vs. 10.5) at a sheet density of 600 to 22% at a sheet density of 700. It should be pointed out that the red pine tear values for thinnings at sheet densities of 700 and 750 are very low for conifer pulps. The values are equivalent to the tear

Table 22. Physical properties of unbleached kappa 50 and kappa 30 pulps.

Wood Type	No. of Revs.	CSF, mL	Sheet Density, kg/m^3	Burst Index, kPa·m^2/g	Tear Index, mN·m^2/g	Breaking Length, Km	TEA, J/m^2
			Kappa 50 Pulps				
Red pine thinnings	0	725	600	5.2	9.7	9.0	92
	250	665	690	7.2	8.4	10.3	128
	325	590	723	8.0	7.7	12.1	151
	500	520	728	8.2	7.5	10.8	114
	575	460	746	7.8	7.3	11.3	132
	650	365	779	8.4	7.3	11.0	124
Red pine mature wood	0	730	425	2.5	21.5	5.1	26
	200	670	597	6.8	14.8	9.7	89
	500	590	616	7.2	13.9	10.6	112
	625	510	712	7.8	12.7	10.7	123
	750	410	650	8.1	12.7	11.7	133
	900	335	646	8.4	12.0	11.7	138
			Kappa 30 Pulps				
Red pine thinnings	0	720	612	4.5	11.3	7.6	75
	100	660	710	6.9	8.6	10.1	109
	200	600	724	7.8	8.1	10.5	114
	400	530	751	8.1	7.5	11.0	132
	500	430	758	8.1	7.2	10.8	119
	600	370	754	8.4	7.3	11.6	136
Red pine mature wood	0	725	491	2.8	21.8	5.3	31
	250	670	611	7.1	14.6	10.8	106
	325	610	611	7.5	13.6	10.6	102
	500	515	671	8.0	12.4	11.0	108
	575	405	652	8.0	12.3	9.7	92
	650	330	657	8.3	11.5	11.1	112

strength of good quality, short-fiber hardwood pulps. Pulps from red pine thinnings cannot be expected to perform satisfactorily where high tear strength is required.

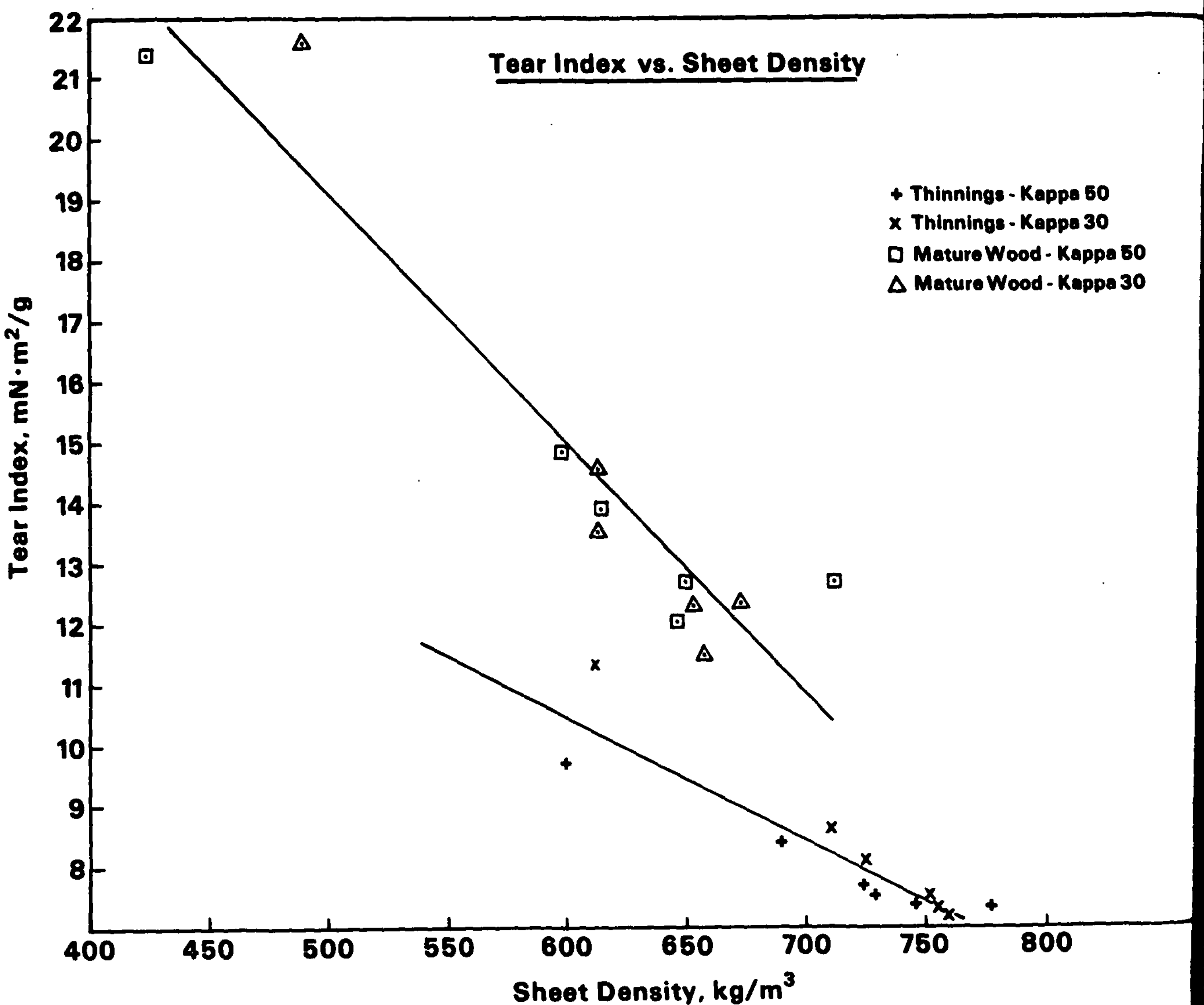

Figure 13. Tear index for mature red pine pulp was much greater than that for red pine thinnings.

Tensile strength (breaking length) normally increases as the level of refining and sheet density increases. Red pine pulps behaved as expected and differences between mature and thinning wood pulps were relatively small. Regression analysis of combined kappa 30 and kappa 50 data showed that tensile strength for the mature wood pulps was 12% greater at 600 sheet density and 15% greater at sheet density 700 (Fig. 14). Only tensile strength differences at sheet densities of 700 kg/m^3 and greater were statistically significant.

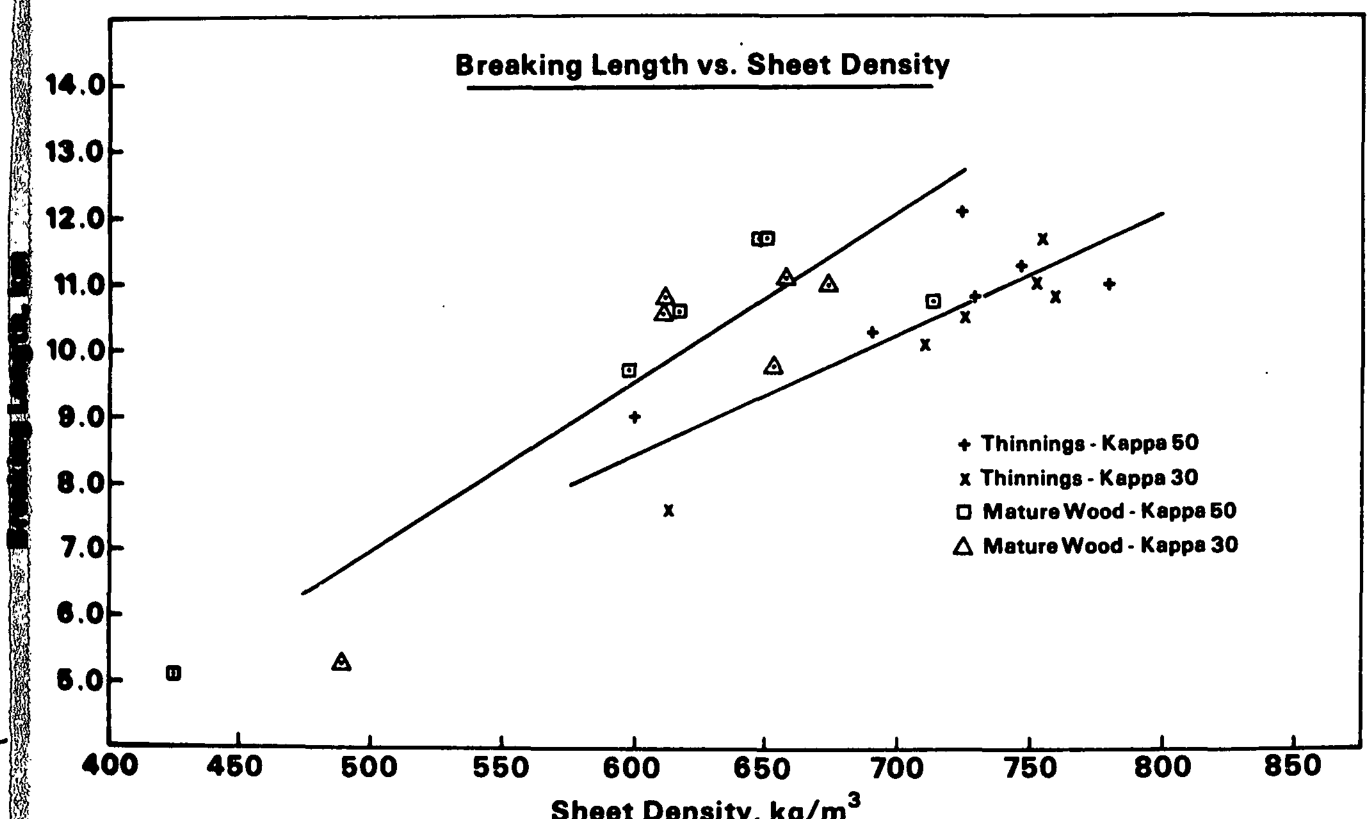

Figure 14. Breaking length (tensile strength) of the mature wood red pine pulps was modestly greater than that of the pulps from red pine thinnings at higher sheet densities.

Like tensile strength, bursting strength usually increases with refining and sheet density. Figure 15 illustrates the bursting strength differences that existed between the two sources of pulp when the kappa 30 and kappa 50 data were plotted over sheet density. As expected the red pine thinning pulps produced handsheets of higher sheet density. When, however, burst is compared at comparable sheet densities, the mature wood pulps have burst values that are 22 to 26% greater (6.6 vs. 4.9 at 600 sheet density).

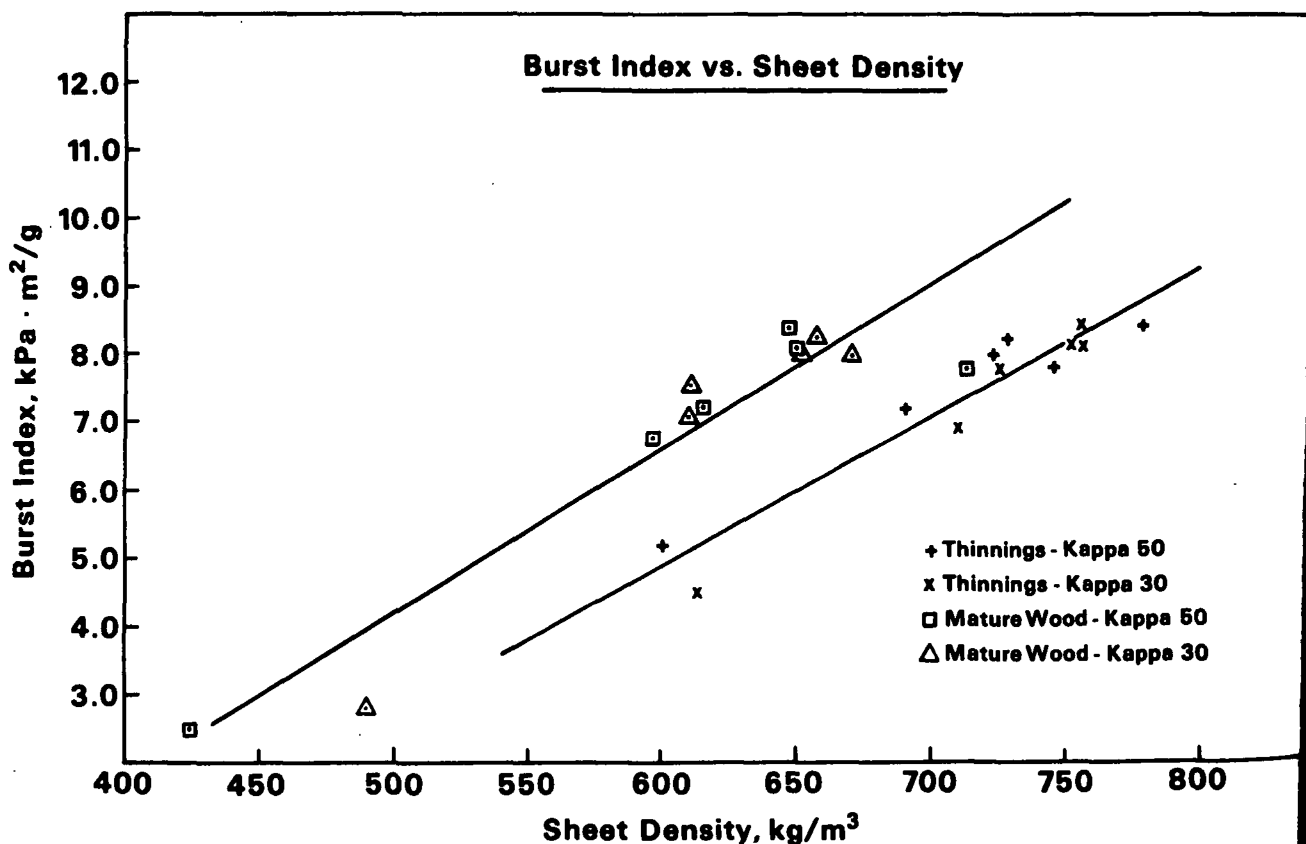

Figure 15. Pulp from mature wood had 22 to 26% greater burst index than pulps produced from red pine thinnings.

Tensile energy absorption (TEA), which is a measure of the ability of the paper to absorb energy prior to tensile failure, is an important property of multiwall sacks and packaging, converting, and wrapping papers. When the TEA for the two types of pulp were compared at the same sheet density, the source of wood (mature vs. thinnings) had only a minor influence on TEA values. Mature wood pulps were about 16% greater at a sheet density of 700 and were the same at a sheet density of 600 (see Fig. 16). Kappa 30 and 50 pulps from thinnings had comparable TEA values, whereas mature wood kappa 30 pulps had lower TEA when compared with mature wood kappa 50 pulps at equivalent freeness levels.

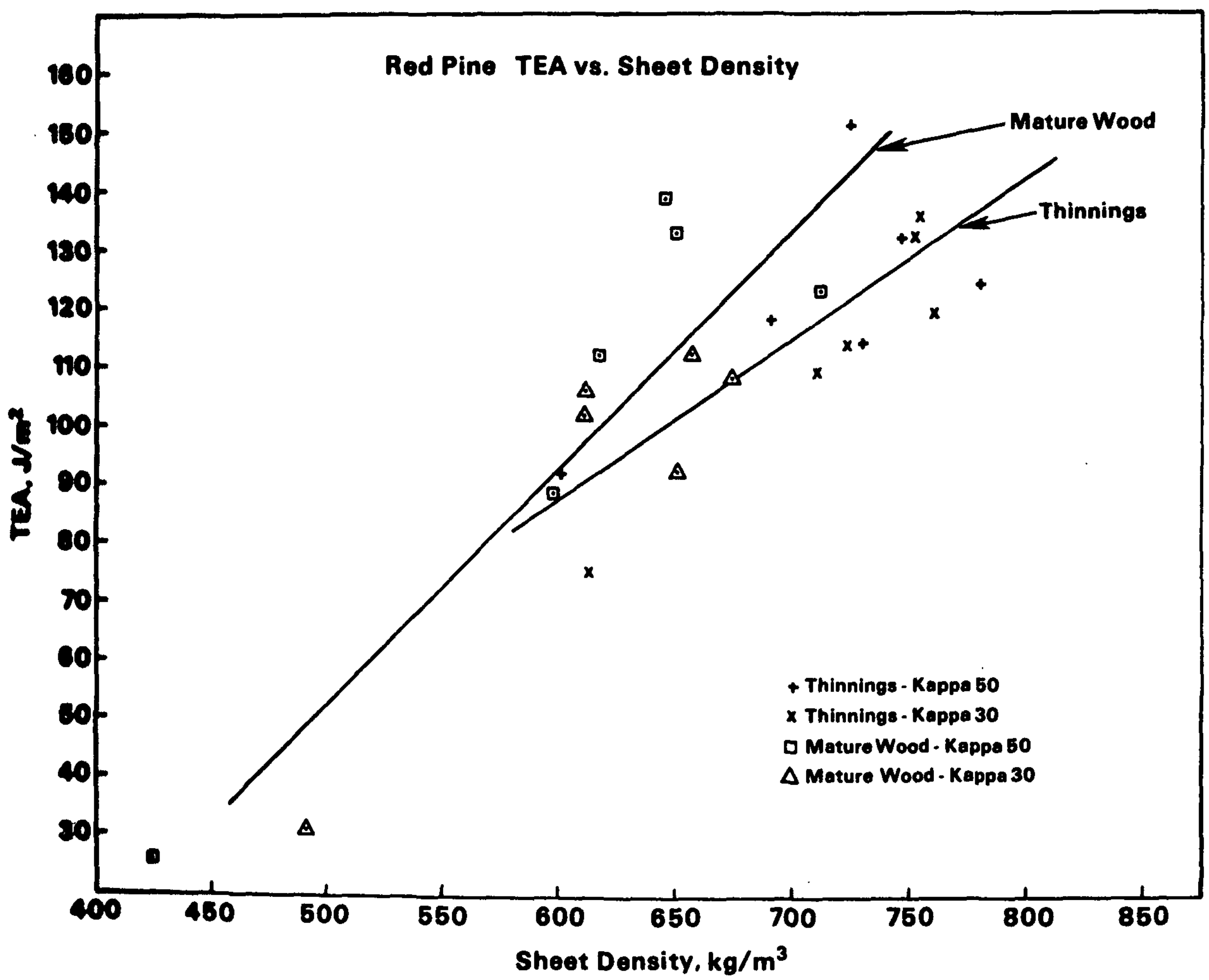

Figure 16. The differences in TEA regression lines for the two sources of red pine chips are not statistically significant.

Another method of comparing the usefulness of a pulp is to plot a strength property of interest over breaking length. The reasoning in this approach is that the end product requires a certain minimum breaking length and refining is done to obtain it. By plotting various strength properties over breaking length, it is possible to see what happens to these properties when the pulp is refined to obtain the needed tensile strength. Figure 17 is a plot of TEA over breaking length for the two sources of red pine pulps. Again, there appears to be only a minor influence of wood source on TEA. When a single regression line is calculated for these data, all of the mature wood kappa 30 pulps fall below the regression line, suggesting mature wood kappa 30 pulps have lower TEA than comparable kappa 50 pulps.

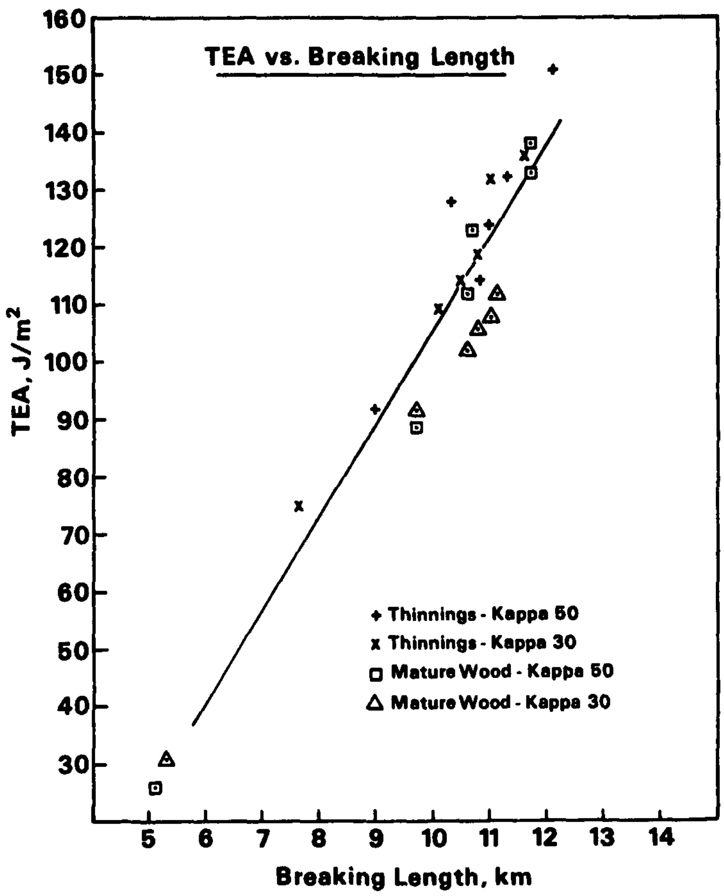

Figure 17. TEA increases as breaking length increases with no difference between red pine wood sources or TEA.

CONCLUSIONS

This kraft pulping study had the objective of evaluating the usefulness of red pine thinnings as a conifer fiber source. Additionally, the study was designed to compare the pulps produced with mature red pine pulps and the previously evaluated pulps from mature jack pine and larch species thinnings. The wood from the 24-year-old red pine thinnings was low in specific gravity (0.32), consisted of 82% juvenile wood, and produced pulp yields that were 2 to 3% lower than yields from mature red pine chips. Additionally the thinning pulps had Cuene viscosities 4 to 6 units lower than the mature wood pulps. Pulping rates, based upon H-factor/kappa number comparisons, were the same for the two red pine wood sources, but both of them pulped much faster than the earlier evaluated larch and jack pine chips.

The pulps from red pine thinnings, when evaluated at comparable sheet densities, had much lower tear (22 to 30%), much lower burst (22 to 26%), lower breaking length (12 to 15%), and equivalent TEA values when compared with pulps produced from mature red pine chips.

COMPARISONS WITH EARLIER EVALUATED JACK PINE AND LARCH SPECIES

The usefulness of pulp from red pine thinnings was evaluated further by comparing the data generated in the above described study with the yield, pulping rate, and paper strength information published earlier for mature jack pine and plantation larch.

Comparing the red pine pulping rate data with those for jack pine and larch species shows that both red pine thinnings and mature wood pulped with much greater ease (Fig. 18). At kappa 30, for example, H-factor values for red pine were 17% less (1518 vs. 1832) than for age 18 European larch plantation trees. Differences were even greater when the comparison was made with Japanese and hybrid larch.

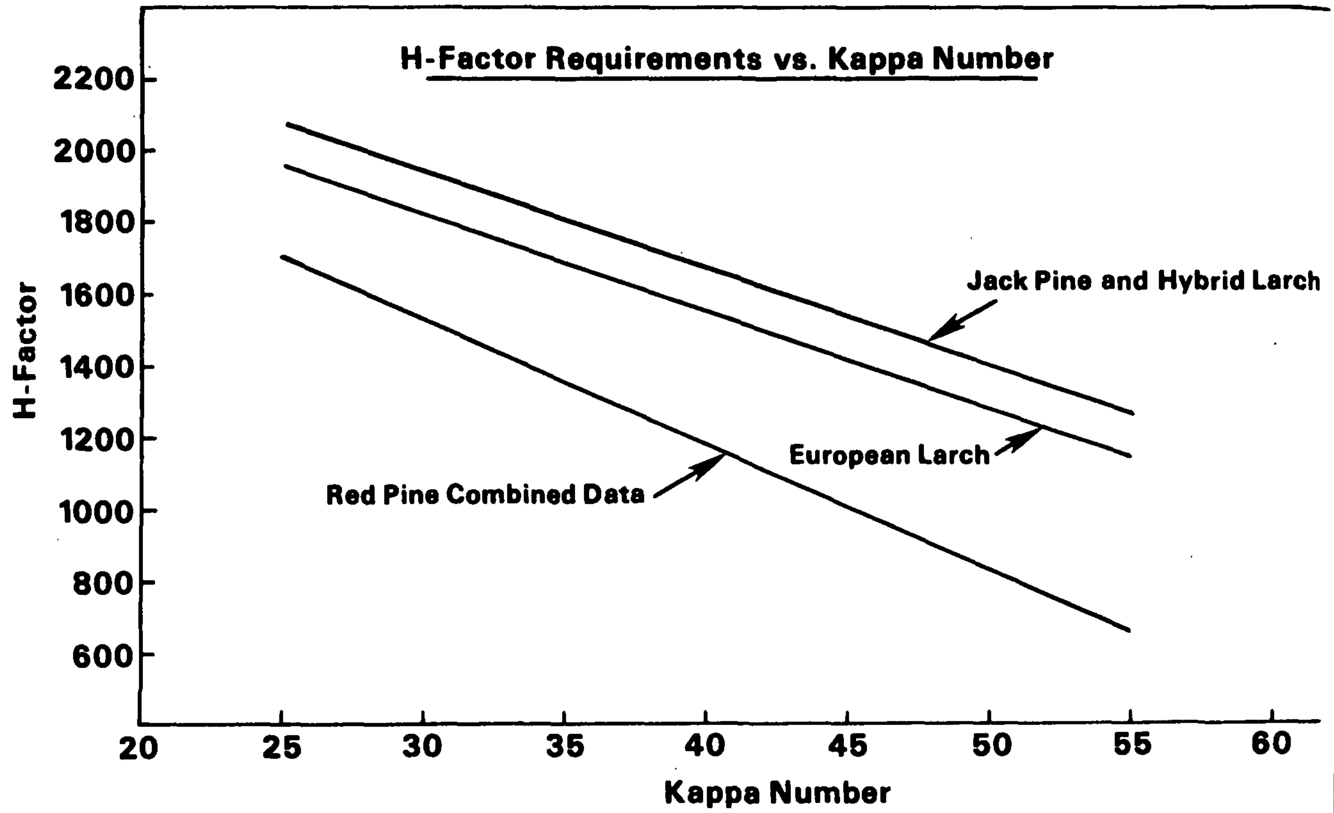

Figure 18. Comparison of H-factor requirements vs. kappa number for red pine with similar data for European larch, jack pine, and hybrid larch.

Table 23 summarizes the kraft pulp yield data available from this and earlier studies.[8] All data have been adjusted to kappa 35 to facilitate comparisons. As can be seen from these data, the pulp yields from thinnings evaluated in this latest study were comparable to yield data from young red pine plantation trees evaluated by a cooperating company (45.7 vs. 46%) in an earlier study. This comparison suggests red pine thinnings (age 24 years) have unscreened pulp yields (45.7% at kappa 35) that are similar to Japanese larch, and jack pine plantation trees and are less than red pine "mature wood," European larch plantation trees, and hybrid larch plantation trees.

Table 23. Summary of kraft pulp yields.

Material	Tree Age, year	Kappa 35 Unscreened Pulp Yield, %[a]	Data Source
Red pine plantation trees[b]	22	46.0	3409 Progress Report Three
Jack pine plantation trees[b]	25	45.0	3409 Progress Report Three
European larch plantation trees	18	48.0	3409 Progress Report Three
Japanese larch plantation trees	22	45.6	3409 Progress Report Three
Hybrid larch plantation trees	23	49.2	3409 Progress Report Three
Jack pine pulpwood bolts	55	44.6	3409 Progress Report Three
Red pine plantation "thinnings"	24	45.7	3409 Progress Report Seven
Red pine plantation "mature wood"	49	48.5	3409 Progress Report Seven

[a]All pulp yields were adjusted to kappa 35.
[b]Data provided by a cooperating firm.

Ease of refining of pulps from red pine thinnings was similar to that for red pine mature wood, and was less than that for hybrid and Japanese larch and less, but similar, to that for young European larch and mature jack pine pulps. These results are not unexpected when the low specific gravity and high percentage of juvenile wood present in the chips of red pine thinnings are considered.

The red pine thinning pulps developed adequate breaking length (tensile strength) when refined and had values comparable to jack pine and larch pulps (see Fig. 19). Figures 20, 21, and 22 illustrate what happens to tear, burst, and TEA when red pine thinnings are refined to obtain a satisfactory breaking length. The newly generated data were plotted with the results from the earlier evaluated larch and jack pine. This approach allows the comparison of the strength properties of pulps from red pine thinnings with information from the above species at a constant breaking length. Briefly, these pulp strength comparisons demonstrated that pulps from red pine thinnings, at breaking length 10, for example, had

1. 32% lower tear index (12.9 _vs._ 8.8),
2. 13% lower burst index (7.8 _vs._ 6.8), and
3. 20% lower TEA (132.5 _vs._ 105.5)

than pulps from 18-year-old European larch. Comparisons at other breaking length levels are possible using the data in these figures.

Pulps from red pine thinnings represent a trade off when compared with the larch species of interest to Project 3409. Red pine cooks rapidly, refines easily, has only moderately lower pulp yields, develops good tensile strength but has much lower tearing strength and has modestly but significantly lower burst index and TEA. Product end-use requirements must be considered when making the choice of species for emphasis in forest management.

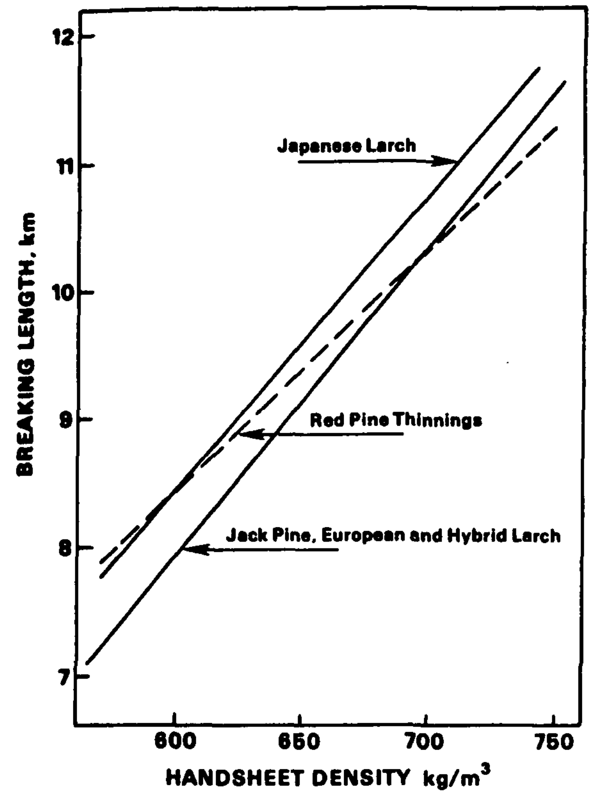

Figure 19. Breaking length vs. handsheet density. Red pine thinnings have breaking length values that are similar to jack pine and Japanese, European, and hybrid larch.

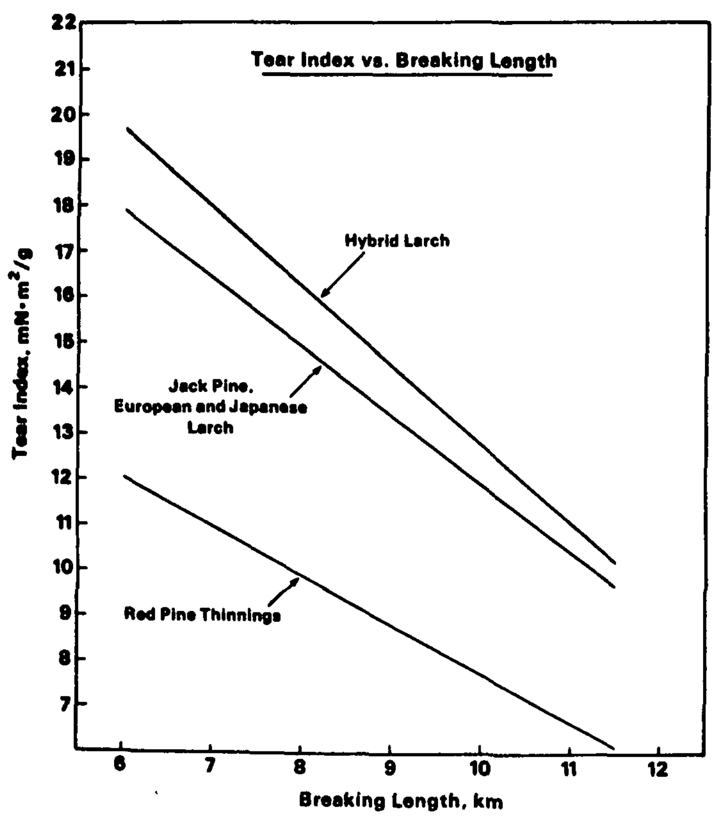

Figure 20. Red pine thinnings produced pulps that had much lower tearing strength than jack pine and larch pulps.

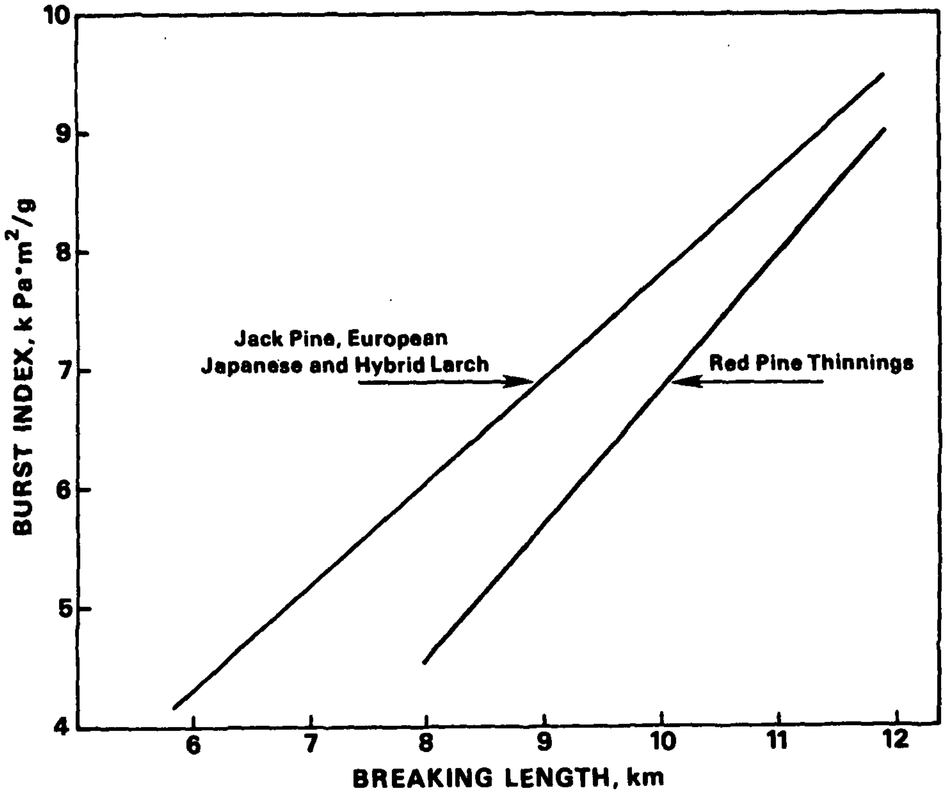

Figure 21. Burst index vs. breaking length. Burst index is lower for red pin(pulps than for jack pine and larch pulps. At breaking length 10 the difference is approximately 13%.

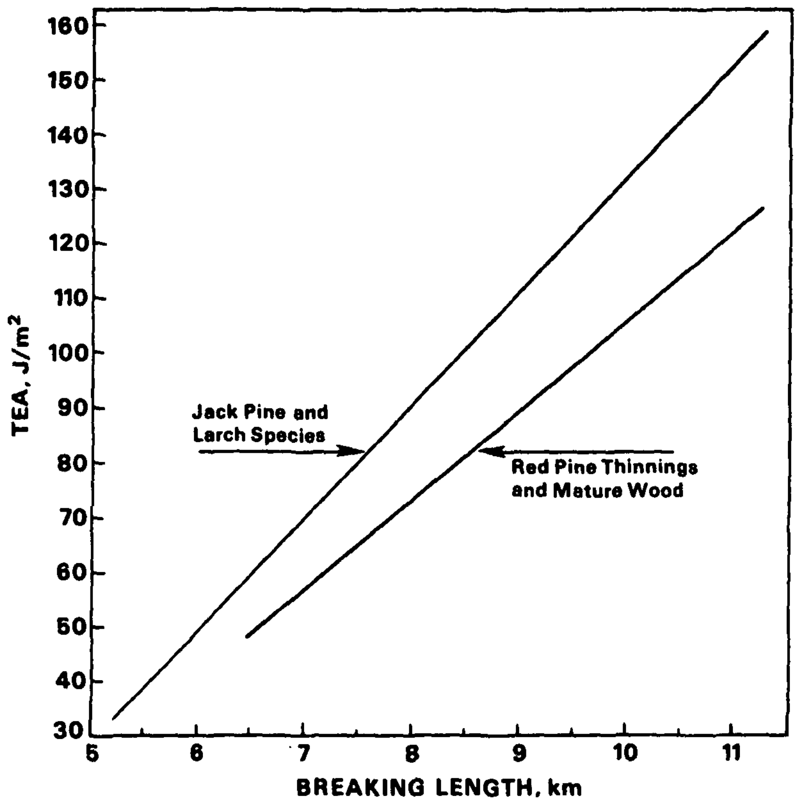

Figure 22. TEA vs. breaking length. Comparison of red pine pulps with larcl and jack pine pulps at a standard breaking length demonstrates tl magnitude of differences in TEA that exist.

PLANS FOR 1987/88

Work in the coming year will emphasize the grafting of clones for a hybrid seed orchard and for the completion of orchards already established. Some exploratory work will be done on laboratory methods for evaluating frost tolerance. In addition, the suitability of tamarack as a pulping species will be evaluated in cooperation with the IPC pulping group as part of their ongoing pure species pulping effort. If pulping results and cooperator interest indicate work with tamarack is warranted, parent tree selection will begin. The possibility of introducing Canadian larch clones will be explored, with the major problem being the restriction of *Larix* movement into the U.S. Controlled pollination work will be expanded this spring to improve methods. Herbicide screening will be undertaken at the IPC Greenville Nursery in an effort to find compatible herbicides for use with *Larix*.

ACKNOWLEDGMENTS

The authors of this report are indebted to Egon Humenberger and Bob Arvey for their assistance in field measurements, nursery and greenhouse maintenance, grafting, seed orchard establishment, and wood collections. The cooperation of the Institute's Pulping and Bleaching Roup, who shared in large part the cost of the red pine pulping study and carried out the extensive pulping and bleaching work is gratefully acknowledged. Particular thanks go to Tom McDonough and Salman Aziz for supervising the study and summarizing the results. Thanks also to Pete Van Drunen for carrying out the pulping work. Th assistance of the Institute's Editorial and Publications Department, in particular Betty Dorman and her attention to typing and preparing this report is greatly appreciated. We would also like to thank David Maass of Scott Paper Company for his ongoing quest for larch selections in the Northeast and his willingness to provide them for project use. Also acknowledged is the assistance of Martin Rech and his staff at Consolidated Papers in providing access for wood collections and providing a site for herbicide screening. Thanks also to John Johnson of Mead Corporation for his willingness to grow larch seedlings and plant them in replicated trials. The willingness and assistance provided by several cooperators in establishing field plantings and seed orchards is also greatly appreciated.

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APPENDIX

Table 24. European larch parent tree selections.

Material	Origin	Distribution Group[a]	Clone Origin
LD-10-79	Styria, Austria	Alpen	Wisconsin DNR, LaCrosse, WI
LD-11-79	Styria, Austria	Alpen	Wisconsin DNR, LaCrosse, WI
LD-12-79	Styria, Austria	Alpen	Wisconsin DNR, LaCrosse, WI
LD-1-80	Breslau, Poland	Sudeten	Iowa Conservation Commission, McGregor, IA
LD-2-80	Breslau, Poland	Sudeten	Iowa Conservation Commission, McGregor, IA
LD-3-80	Wroclaw, Poland	Sudeten	Iowa Conservation Commission, McGregor, IA
LD-4-80	Breslau, Poland	Sudeten	Iowa Conservation Commission, McGregor, IA
LD-5-80	Styria, Austria	Alpen	Wisconsin DNR, LaCrosse, WI
LD-6-80	Styria, Austria	Alpen	Wisconsin DNR, LaCrosse, WI
LD-7-80	Styria, Austria	Alpen	Wisconsin DNR, LaCrosse, WI
LD-8-80	SSUI[b]	Alpen	Wisconsin DNR, LaCrosse, WI
LD-9-80	SSUI[b]	Alpen	Wisconsin DNR, LaCrosse, WI
LD-10-80	SSUI[b]	Alpen	Wisconsin DNR, LaCrosse, WI
LD-11-80	Tirol, Austria	Alpen	Wisconsin DNR, LaCrosse, WI
LD-12-80	Rundforbi, Denmark	Sudeten	Canadian Forestry Service, Chalk River, Ont.
LD-13-80	Rundforbi, Denmark	Sudeten	Canadian Forestry Service, Chalk River, Ont.
LD-14-80	Rundforbi, Denmark	Sudeten	Canadian Forestry Service, Chalk River, Ont.
LD-15-80	Rundforbi, Denmark	Sudeten	Canadian Forestry Service, Chalk River, Ont.
LD-16-80	Zagnansk, Poland	Sudeten	Canadian Forestry Service, Chalk River, Ont.
LD-17-80	Zagnansk, Poland	Sudeten	Canadian Forestry Service, Chalk River, Ont.
LD-18-80	Unknown	Unknown	U.S. Forest Service, Rhinelander, WI
LD-19-80	Nodebo, Denmark	Sudeten[b]	Danish Forest Service, Humlebaek, Denmark
LD-20-80	Kronborg, Denmark	SSUI[b]	Danish Forest Service, Humlebaek, Denmark
LD-21-80	Palsgaard, Denmark	Sudeten	Danish Forest Service, Humlebaek, Denmark
LD-22-80	Nodebo, Denmark	Sudeten	Danish Forest Service, Humlebaek, Denmark
LD-23-80	Unknown	Unknown	Hammermill Paper Co., Warren, PA
LD-24-80	Unknown	Unknown	Hammermill Paper Co., Warren, PA
LD-25-80	Unknown	Unknown	Hammermill Paper Co., Cattaraugus, NY
LD-26-80	Unknown	Unknown	Hammermill Paper Co., Warren, PA
LD-27-80	Unknown	Unknown	Hammermill Paper Co., Warren, PA
LD-28-80	Unknown	Unknown	Hammermill Paper Co., Mina Hollow, PA
LD-29-80	Unknown	Unknown	Hammermill Paper Co., Mina Hollow, PA
LD-30-80	Unknown	Unknown	Hammermill Paper Co., Mina Hollow, PA
LD-31-80	Unknown	Unknown	Hammermill Paper Co., Mina Hollow, PA
LD-1-81	Rundforbi, Denmark	Sudeten	Canadian Forestry Service, Chalk River, Ont.
LD-2-81	Zagnansk, Poland	Polen	Canadian Forestry Service, Chalk River, Ont.
LD-3-81	Aroretet, Denmark	Unknown	Danish Forest Service, Humlebaek, Denmark
LD-4-81	Palsgaard, Denmark	Polen	Danish Forest Service, Humlebaek, Denmark
LD-5-81	Nodebo, Denmark	Polen	Danish Forest Service, Humlebaek, Denmark
LD-6-81	Palsgaard, Denmark	Polen	Danish Forest Service, Humlebaek, Denmark
LD-7-81	Unknown	Unknown	Hammermill Paper Co., Warren, PA
LD-8-81	Unknown	Unknown	Hammermill Paper Co., Potter, PA
LD-9-81	Unknown	Unknown	Hammermill Paper Co., Potter, PA
LD-10-81	Unknown	Unknown	Hammermill Paper Co., Potter, PA
LD-11-81	Unknown	Unknown	Hammermill Paper Co., Warren, PA
LD-12-81	Unknown	Unknown	Scott Paper Co., Waterville, ME
LD-13-81	SSUI[b]	SSUI	Scott Paper Co., Waterville, ME

See end of table for footnotes.

Table 24 (Continued). European larch parent tree selections.

Material	Origin	Distribution Group[a]	Clone Origin
LD-1-82	Zagnansk, Poland	Polen	Canadian Forestry Service, Chalk River, Ont.
LD-2-82	Lot 55, Sweden	SSUI	Canadian Forestry Service, Chalk River, Ont.
LD-3-82	Zagnansk, Poland	Polen	Canadian Forestry Service, Chalk River, Ont.
LD-4-82	Berthierville, Quebec	SSUI	Ministry of Lands & Forests, Quebec, Canada
LD-5-82	Berthierville, Quebec	SSUI	Ministry of Lands & Forests, Quebec, Canada
LD-6-82	Berthierville, Quebec	SSUI	Ministry of Lands & Forests, Quebec, Canada
LD-7-82	Berthierville, Quebec	SSUI	Ministry of Lands & Forests, Quebec, Canada
LD-8-82	Berthierville, Quebec	SSUI	Ministry of Lands & Forests, Quebec, Canada
LD-9-82	Berthierville, Quebec	SSUI	Ministry of Lands & Forests, Quebec, Canada
LD-10-82	Berthierville, Quebec	SSUI	Ministry of Lands & Forests, Quebec, Canada
LD-11-82	Dobris, Czechoslovakia	SSUI	University of Michigan, Ann Arbor, MI
LD-12-82	Dobris, Czechoslovakia	SSUI	University of Michigan, Ann Arbor, MI
LD-13-82	Zabreh-Dubicko, Czechoslovakia	Sudeten	University of Michigan, Ann Arbor, MI
LD-14-82	Ruda nad Morovou, Czechoslovakia	Sudeten	University of Michigan, Ann Arbor, MI
LD-15-82	Skarzysko, Poland	Polen	Canadian Forestry Service, Fredericton, N.B.
LD-16-82	Skarzysko, Poland	Polen	Canadian Forestry Service, Fredericton, N.B.
LD-17-82	Schlitz, Germany	SSUI	University of Michigan, Ann Arbor, MI
LD-18-82	Skarzysko, Poland	Polen	Canadian Forestry Service, Fredericton, N.B.
LD-19-82	Schlitz, Germany	SSUI	University of Michigan, Ann Arbor, MI
LD-20-82	Unknown	Unknown	Diamond International, Milo, ME
LD-22-82	Pinczow, Poland	Polen	State of New Hampshire, Hillsboro, NH
LD-23-82	Salzburg, Austria	Alpen	State of New Hampshire, Hillsboro, NH
LD-24-82	Brenensky, Czechoslovakia	Sudeten	State of New Hampshire, Hillsboro, NH
LD-26-82	Salzburg, (Bluhnbach) Austria	Alpen	State of New Hampshire, Hillsboro, NH
LD-27-82	SSUI	SSUI	University of Maine, Orono, ME
LD-28-82	SSUI	SSUI	University of Maine, Orono, ME
LD-1-83	SSUI	SSUI	Champion International, Nathan, MI
LD-2-83	Val di Fiemme, Italy	Alpen	State of New Hampshire, Hillsboro, NH
LD-3-83	County Moray, Scotland	SSUI	State of New Hampshire, Hillsboro, NH
LD-1-84	SSUI	SSUI	State of Maine, Atkinson, ME
LD-1-85	Kroscienko Forest Dist. Poland	Polen	IPC Larch Trial I, Eagle River, WI
LD-1-86	Morayshire, Scotland	SSUI	Harvard Forest, MA
LD-2-86	Morayshire, Scotland	SSUI	Harvard Forest, MA
LD-3-86	Czechoslovakia	SSUI	Arnold Arboretum, MA

[a] Four separate distributional groups are recognized within the geographical range of European larch: Alpen, Sudeten, Tatra, and Polen plus several smaller outliers in Rumania. Major genetic differences are found between and within these groupings.
[b] Seed source under investigation.

Table 25. *Japanese larch parent tree selections.*

Material	Origin	Clone Origin
LL-4-59,S-1	Nagano Prefecture, Japan	IPC Larch Trial III, Clintonville, WI
LL-4-59,S-2	Nagano Prefecture, Japan	IPC Larch Trial III, Clintonville, WI
LL-12-59,S-1	Hokkaido, Japan	IPC Larch Trial III, Clintonville, WI
LL-1-80	Nagano Prefecture, Japan	Iowa Conservation Commission, McGregor, IA
LL-2-80	Nagano Prefecture, Japan	Iowa Conservation Commission, McGregor, IA
LL-3-80	Nagano Prefecture, Japan	Iowa Conservation Commission, McGregor, IA
LL-4-80	Nagano Prefecture, Japan	Iowa Conservation Commission, McGregor, IA
LL-5-80	Tochigi Prefecture, Japan	Iowa Conservation Commission, McGregor, IA
LL-6-80	Tochigi Prefecture, Japan	Iowa Conservation Commission, McGregor, IA
LL-7-80	Nagano Prefecture, Japan	Iowa Conservation Commission, McGregor, IA
LL-8-80	Nagano Prefecture, Japan	Iowa Conservation Commission, McGregor, IA
LL-9-80	Latitude 35° 54', longitude 137° 34'	Packaging Corporation of America, Bear Lake, MI
LL-10-80	Latitude 35° 54', longitude 137° 34'	Packaging Corporation of America, Bear Lake, MI
LL-11-80	SSUI[a]	Pennsylvania Bureau of Forestry, Harrisburg, PA
LL-12-80	SSUI[a]	Pennsylvania Bureau of Forestry, Harrisburg, PA
LL-13-80	SSUI[a]	Pennsylvania Bureau of Forestry, Harrisburg, PA
LL-14-80	SSUI[a]	Pennsylvania Bureau of Forestry, Harrisburg, PA
LL-15-80	SSUI[a]	Pennsylvania Bureau of Forestry, Harrisburg, PA
LL-16-80	SSUI[a]	Pennsylvania Bureau of Forestry, Harrisburg, PA
LL-17-80	SSUI[a]	Canadian Forestry Service, Chalk River, Ont.
LL-18-80	SSUI[a]	Canadian Forestry Service, Chalk River, Ont.
LL-19-80	SSUI[a]	Canadian Forestry Service, Chalk River, Ont.
LL-20-80	SSUI[a]	Canadian Forestry Service, Chalk River, Ont.
LL-21-80	SSUI[a]	Canadian Forestry Service, Chalk River, Ont.
LL-22-80	Unknown	Canadian Forestry Service, Chalk River, Ont.
LL-23-80	Unknown	Glatfelter Pulp Wood Co., Hershey, PA
LL-24-80	Unknown	Glatfelter Pulp Wood Co., Hershey, PA
LL-1-81	SSUI[a]	U.S. Forest Service, Rhinelander, WI
LL-3-81	Nagano Prefecture, Japan	Canadian Forestry Service, Chalk River, Ont.
LL-4-81	Gumma Prefecture, Japan	Canadian Forestry Service, Chalk River, Ont.
LL-6-81	Nagano Prefecture, Japan	Canadian Forestry Service, Chalk River, Ont.
LL-7-81	Nagano Prefecture, Japan	Canadian Forestry Service, Chalk River, Ont.
LL-8-81	Nagano Prefecture, Japan	Canadian Forestry Service, Chalk River, Ont.
LL-9-81	Nagano Prefecture, Japan	Canadian Forestry Service, Chalk River, Ont.
LL-10-81	Nagano Prefecture, Japan	Canadian Forestry Service, Chalk River, Ont.
LL-11-81	Nagano Prefecture, Japan	Canadian Forestry Service, Chalk River, Ont.
LL-12-81	SSUI[a]	Scott Paper Co., Oxford City, ME
LL-2-59,S-1	Nagano Prefecture, Japan	IPC Larch Trial III, Clintonville, WI
LL-5-82	Hokkaido, Japan	IPC Larch Trial I, Eagle River, WI
LL-6-82	Hokkaido, Japan	IPC Larch Trial I, Eagle River, WI
LL-7-82	SSUI	International Paper Co., Readfield, ME
LL-8-82	SSUI	Glatfelter Pulp Wood Co., Fort Littleton, PA
LL-9-82	Yokohama, Japan	Glatfelter Pulp Wood Co., Huston, PA
LL-10-82	Yokohama, Japan	Glatfelter Pulp Wood Co., Maddensville, PA
LL-11-82	Yokohama, Japan	Glatfelter Pulp Wood Co., Huston, PA
LL-12-82	Yokohama, Japan	Glatfelter Pulp Wood Co., Huston, PA
LL-13-82	SSUI	Diamond International, Milo, ME
LL-1-83	Yatsuga Mts., Japan	University of Wisconsin, Rhinelander, WI
LL-2-83	Yatsuga Mts., Japan	University of Wisconsin, Rhinelander, WI
LL-3-83	Yatsuga Mts., Japan	University of Wisconsin, Rhinelander, WI
LL-4-83	SSUI	University of Wisconsin, Rhinelander, WI
LL-5-83	SSUI	University of Wisconsin, Rhinelander, WI
LL-6-83	Unknown	State of New Hampshire, Hillsboro, NH
LL-7-83	Central Japan	State of New Hampshire, Hillsboro, NH

[a]Seed source under investigation.

Table 26. <u>Larix gmelini</u> and <u>Larix dahurica</u> parent tree selections seed origin.

Material	Origin	Cooperator and Location
LDa-14-59, S-1	Hokkaido, Japan	IPC Larch Trial III, Clintonville, WI
LDa-14-59, S-2	Hokkaido, Japan	IPC Larch Trial III, Clintonville, WI
LDa-1-83	Unknown	State of New Hampshire, Hillsboro, NH
LG-13-59, S-1	Hokkaido, Japan	IPC Larch Trial III, Clintonville, WI

GLOSSARY

FOREST GENETICS TERMS

Clone - A group of plants derived from a single individual (ortet) by asexual reproduction. All members (ramets) of a clone have the same genotype and, consequently, tend to be uniform.

Compression wood - Wood of dense structure formed at the bases of some trees and on the underside of branches in conifers.

Cyclophysis - Abnormal growth that occurs in a graft when scion material is collected from too low an area in the crown.

Cytochromes - Cytochrome a, b, and c are heme-containing proteins widely occurring in cells and acting as oxygen carriers during cellular respiration.

F_1 generation - The first generation of a mating. If each parent is true breeding (homozygous), the F_1 individuals always resemble each other.

F_2 generation - The second generation successive to the parents and produced by crossing or selfing the F_1 individuals. The individuals within an F_2 generation characteristically vary greatly when their F_1 parent or parents are heterozygous.

F_3 generation - The third generation produced by intercrossing or selfing F_2 individuals. Individuals within an F_3 generation characteristically vary greatly.

Full-sib - Progeny, irrespective of sex, having the same male and female parent but from separate fertilizations.

Half-sib - Progeny, irrespective of sex, having only one parent in common.

Hedging - Reducing a plant to a more juvenile stage by repeatedly cutting it back and forcing a large number of shoots.

Heterozygosity - Presence in the same plant of both the dominant and recessive gene. A heterozygous individual characteristically does not breed true.

Homozygosity - Presence in a plant of either the dominant or recessive gene but not both. A homozygous individual breeds true when mated with the same genotype for the character(s) in question.

Inbreeding depression - Loss of vigor and/or fertility through intercrossing or selfing related organisms.

Isozyme (isoenzyme) - Multiple forms of a single enzyme. Isozymes often have different isoelectric points and therefore can be separated by electrophoresis.

Plagiotropism - A growth response to gravity, so that the axis of the plant member makes an angle other than 90° with the line of the gravitational field. See cyclophysis and topophysis.

Propagule - A plant part, such as a bud, tuber, root, or shoot, used to reproduce an individual asexually.

Provenance - The original geographic source of seed or propagules.

Topophysis - Abnormal growth that occurs in a graft when scion material is collected from the wrong branch positions.

PULPING AND SOLID WOOD PRODUCT TERMS

Basic density - Specific gravity of wood based on green volume. The term basic is applied, since both green volume and ovendry weight are as nearly constant and reproducible measurements as can be obtained with wood.

Breaking length - The length of a strip, usually expressed in meters, which would break of its own weight when suspended vertically.

Bursting strength - The hydrostatic pressure in pounds per square inch required to produce rupture of the material when pressure is applied at a controlled increasing rate through a rubber diaphragm to a circular area.

CEDED bleaching - Sequence of chlorination, alkali extraction, chlorine dioxide, extraction, and chlorine dioxide.

Coarseness - The weight per unit length of a single fiber. Usually expressed as mg/100 m and considered to be useful in predicting fiber behavior in paper-making.

Density - Mass per unit volume; i.e., grams per cubic centimeter; lbs per cubic foot. See specific gravity.

Freeness - A measure of the rate at which water drains from a stock suspension through a wire mesh screen or a perforated plate. It is also known as "slowness" or "wetness" according to the type of instrument used in its measurement and the method of reporting results.

Furnish - The mixture of various materials that are blended in the stock suspension from which paper or board is made. The chief constituents are the fibrous material (pulp), sizing materials, wet-strength or other additives, fillers, and dyes.

Handsheet - A sheet made from a suspension of fibers in water, with or without the addition of sizing, loading, or coloring agents. Each sheet is formed separately by draining a pulp suspension on a stationary mold called a sheet mold. It is generally used for testing the physical properties of the pulp and/or the combinations of pulp with other material, in which case the sheet must be formed in accordance with standard procedures.

Kappa no. - Related to the amount of lignin left in the pulp. Decreasing numbers mean less lignin left in the pulp.

Modulus of elasticity - The proportionality constant (K) relating stress and deformation; it indicates the ability of the material to recover its original shape and size after the stress is removed.

Modulus of rupture - The maximum bending load to failure in pounds per square inch.

Specific gravity - The ratio of weight of a substance to the weight of an equal volume of water. Usually expressed as moisture free weight over green volume.

Spiral grain - Grain in which the fibers are aligned in a helical orientation around the axis of the stem.

Tearing resistance - The force required to tear a specimen under standardized conditions. There are three terms in common usage: (1) internal (or continuing) tearing resistance, wherein the edge of the specimen is cut prior to the actual tear. The value is commonly expressed in grams of force required to tear a single sheet. (2) "Edge tearing resistance." (3) Torsion tearing resistance of paper or paperboard is the energy expended in propagating a tear when the tearing force is applied in such a manner as to create a twist or torque.

Tensile strength - The force, parallel with the plane of the paper, required to produce failure in a specimen of specified width and length under specified conditions of loading. This definition must be distinguished from that which is commonly used in engineering practice and which expresses the tensile strength in force per unit area. In the paper industry, it is expressed as load per unit width or as "breaking length."

Zero-span tensile strength - The tensile strength of a sheet of fibrous material, measured with special jaws, at an apparent initial span of zero. It is an indication of the strength of the material comprising the fiber.